TOSHIBA

Radio-Frequency Semiconductors Transistors, FETs, Cell Packs

TOSHIBA CORPORATION
Semiconductor Company

Preface

Thank you for choosing Toshiba semiconductor products. This is the year 2006 edition of the databook entitled Radio-Frequency Semiconductor Devices – Transistors, FETs and Cell Packs.

From this edition, the Radio-Frequency Semiconductor Devices is published in separate volumes: Radio-Frequency Semiconductor Devices – Diodes, Radio-Frequency Semiconductor Devices – Transistors, FETs and Cell Packs, and Radio-Frequency Semiconductor Devices – Power Devices. Please select the suitable databook for your application.

This databook is designed to be easily understood by engineers who are designing Toshiba Radio-frequency small-signal devices into their products for the first time. No special knowledge of these devices is assumed - the contents includes basic information about the Radio-frequency small-signal devices and the application fields in which they are used. In addition, complete technical specifications facilitate selection of the most appropriate Radio-frequency small-signal device for any given application.

Toshiba are continually updating technical publications. Any comments and suggestions regarding any Toshiba document are most welcome and will be taken into account when subsequent editions are prepared. To receive updates to the information in this databook, or for additional information about the products described in it, please contact your nearest Toshiba office or authorized Toshiba dealer.

January 2006

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[1] Part Number Index

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TA4017FT	U5	896
TA4018F	4018F	900
TA4019F	4019F	906
TA4020FT	U3	911
TA4107F	4107F	914
TA4205FC		919
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TG2210FT	UL	932
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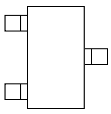
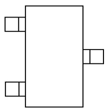
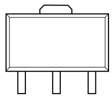
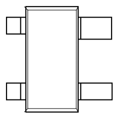
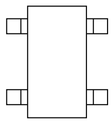
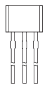
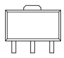
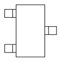
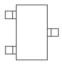
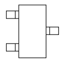
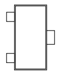
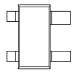
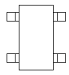
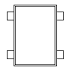
[2] Selection Guide by Packages and Applications

[2] Selection Guide by Packages and Applications

1. Transistors for TV Tuners

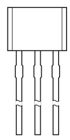
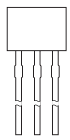
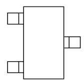
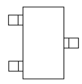
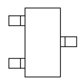
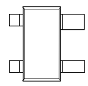
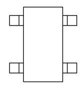
Application			Package Type				
			3 pin			4 pin	
			S-MINI	USM	PW-MINI	SMQ	USQ
							
UHF	RF	MOS				3SK199 3SK207 3SK232 3SK291	3SK256 3SK249 3SK293
UHF	RF	Bipolar		2SC4244		2SC4214	
UHF	MIX	Bipolar	2SC3120 2SC3862	2SC4245			
UHF	OSC		2SC3120 2SC3121 2SC3547A	2SC4245 2SC4246 2SC4247			
VHF	RF	GaAs HBT			MT3S150P		
VHF	RF	MOS				3SK195 3SK225 3SK226 3SK292	3SK259 3SK257 3SK258 3K294
VHF	MIX	Bipolar	2SC3123	2SC4250			
VHF	MIX	MOS					3SK260
VHF	OSC	Bipolar	2SC3124	2SC4251 2SC4252			

2. Transistors for the VHF-to-UHF Band

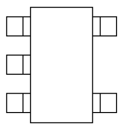
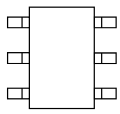
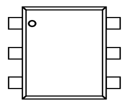
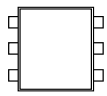
Application		Package Type									
		3 pin							4 pin		
		TO-92	PW-MINI	S-MINI	USM	SSM	TESM	fSM	SMQ	USQ	TESQ
											
VHF-to-UHF Low-Noise Amp	NPN-TR	2SC2498									
				2SC5064	2SC5065	2SC5066	2SC5066FT				
				2SC5084	2SC5085	2SC5086	2SC5086FT		2SC5087, 2SC5087R*	2SC5088	
				2SC5089	2SC5090	2SC5091	2SC5091FT		2SC5092	2SC5093	
				2SC5094	2SC5095	2SC5096	2SC5096FT		2SC5097	2SC5098	
							2SC5317FT			2SC5319	
					2SC5463	2SC5464	2SC5464FT				
					MT3S06U	MT3S06S	MT3S06T	MT3S06FS	MT4S06	MT4S06U	
					MT3S07U	MT3S07S	MT3S07T	MT3S07FS	MT4S07	MT4S07U*	
							MT3S14T*	MT3S14FS*			
					MT3S16U*		MT3S16T*	MT3S16FS*			
							MT3S18T*	MT3S18FS*			
							MT3S35T	MT3S35FS			
							MT3S36T	MT3S36FS			
							MT3S37T	MT3S37FS			
							MT3S41T	MT3S41FS			
							MT3S45T	MT3S45FS			
										MT4S32U	
										MT4S100U	MT4S100T
										MT4S101U	MT4S101T
										MT4S102U	MT4S102T*
										MT4S104U	MT4S104T*
										MT4S200U*	
			MT3S105P								
VHF-to-UHF OSC	NPN-TR			2SC3547A	2SC4247						
				2SC5106	2SC5107	2SC5108	2SC5108FT				
				2SC5109	2SC5110	2SC5111	2SC5111FT				
				MT3S03A*	MT3S03AU	MT3S03AS	MT3S03AT	MT3S03AFS	MT4S03A	MT4S03AU	
				MT3S04A*	MT3S04AU	MT3S04AS	MT3S04AT	MT3S04AFS	MT4S04A	MT4S04AU	
							MT3S05T	MT3S05FS			
							MT3S08T	MT3S08FS			
							MT3S11T	MT3S11FS*			
							MT3S12T				
								MT3S106FS*			
								MT3S107FS*			
								MT3S108FS			
								MT3S109FS*			
								MT3S110FS*			

*: New product

3. Transistors for AM and FM Tuners

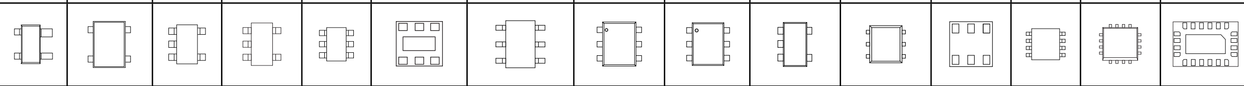
Application			Package Type						
			3 pin					4 pin	
			TO-92	MINI	S-MINI	USM	SSM	SMQ	USQ
									
FM	RF	Dual-Gate MOS						3SK195 3SK225 3SK226 3SK292	3SK257 3SK258 3SK294
		Single-Gate MOS						2SK1771	
		Cascode MOS		2SK241	2SK302	2SK882			
		Cascade J-FET		2SK161	2SK211	2SK881			
		Single-Gate J-FET		2SK192A	2SK210				
		Bipolar	2SC1923	2SC2668	2SC2714	2SC4215	2SC4915		
	MIX	Dual-Gate MOS							3SK260
		Bipolar	2SC1923	2SC2668	2SC2714	2SC4215	2SC4915		
	OSC	Single-Gate J-FET		2SK192A	2SK210				
		Bipolar	2SC1923	2SC2668 2SC2995	2SC2714 2SC2996	2SC4215	2SC4915		
	IF	Bipolar	2SC380TM	2SC2669 2SC2995	2SC2715 2SC2996				
AM	RF	Single-Gate J-FET	2SK709	2SK710	2SK711	2SK1875			
		Bipolar	2SC941TM	2SC2670	2SC2716				
	CONV	Bipolar	2SC380TM 2SC941TM 2SC1815	2SC2669 2SC2670 2SC2458	2SC2715 2SC2716 2SC2712	2SC4116			
	IF	Bipolar	2SC380TM 2SC1815	2SC2669 2SC2458	2SC2715 2SC2712	2SC4116			

4. Dual-Chip Devices

Application	Package Type			
	5 pin	6 pin		
	SMV	TU6	ES6	fS6
				
AM RF (with AGC)	HN3G01J			
VHF-to-UHF Low-Noise Amp			MT6C03AE MT6C04AE	
VHF-to-UHF Buffer + OSC		MT6L03AT	MT6L03AE	
		MT6L04AT	MT6L04AE	
				MT6L05FS
				MT6L11FS*
			MT6L53E	
			MT6L54E	
			MT6L55E	MT6L55FS
			MT6L56E	
			MT6L57AE	
			MT6L58AE	
			MT6L61AE	
			MT6L62AE	
				MT6L63FS*
				MT6L64FS*
				MT6L65FS*
				MT6L66FS*
				MT6L67FS*
				MT6L68FS*
				MT6L71FS*
				MT6L72FS*
				MT6L73FS*
				MT6L74FS*
				MT6L75FS*
				MT6L76FS*
				MT6L77FS*
				MT6L78FS*

*: New product

5. Cell Packs

Application	Package Type														
	4 pin		5 pin		6 pin								8 pin	16 pin	20 pin
	SMQ	TESQ	SMV	USV	SM6	CST6B	TU6	ES6	sES6	ESV	UF6	CS6	SM8	QS16	CST20
															
VHF-to-UHF Wide-Band Amp	TA4001F TA4002F		TA4004F	TA4011FU TA4012FU				TA4016AFE		TA4011AFE TA4012AFE					
VHF-to-UHF DBM													TA4107F		
LNA		TA4020FT*													
SPDT Switch						TG2217CTB*	#TG2210FT #TG2211AFT*		#TG2213S #TG2214S		#TG2216TU				
TCXO							TA4014FT TA4015FT	TA4014FE TA4015FE				TA4014FC			
VCO												TA4205FC			
CATV IF Amp							TA4017FT						TA4018F TA4019F		
LNA + MIX														TA4500F*	
PA + Switch															TG2403CT*

#: GaAs

*: New product

[3]   Main Characteristics

[3] Main Characteristics

1. Transistors for TV Tuners

Application	Part Number	Maximum Ratings			Electrical Characteristics													Package Type
		V_{CEO} (V)	I_C (mA)	P_C (mW)	h_{FE}			f_T (typ.)			Gp ($G_{C°}$)/NF (typ.)					C_{re} (C_{rb}▲) (pF)	C_{ob} (pF)	
						V_{CE} (V)	I_C (mA)	(MHz)	V_{CE} (V)	I_C (mA)	(dB/dB)	V_{CC} (V)	I_C (mA)	V_{AGC} (V)	f (MHz)			
VHF RF	#MT3S150P*	8	90	650	100 to 200	5	50	1700	5	50	10/0.95	5	10	—	1000	0.85	1.15	PW-MINI
VHF MIX	2SC3123	20	50	150	40 to 300	10	5	1400	10	5	23°/3.8	12	3	—	200	0.4	—	S-MINI
	2SC4250	20	50	100	40 to 300	10	5	1400	10	5	25°/4.3	12	3	—	200	0.45	—	USM
VHF OSC	2SC3124	15	50	150	40 to 200	3	8	1100	10	8	—	—	—	—	—	—	0.9	S-MINI
	2SC4251	15	50	100	40 to 200	3	8	1100	10	8	—	—	—	—	—	—	0.9	USM
	2SC4252	12	30	100	40 to 250	10	5	2000	10	5	—	—	—	—	—	—	1.05	USM
UHF RF	2SC4214	20	20	150	40 min.	3	1	850	3	1	15/2.8	4.5	—	2	800	0.3▲	—	SMQ
	2SC4244	20	20	100	40 min.	3	1	850	3	1	17/4	4.5	—	2	800	0.4▲	—	USM
UHF MIX	2SC3862	15	50	150	40 to 200	10	5	2400	10	2	—	—	—	—	—	0.6	—	S-MINI E.B.Rev
UHF MIX/OSC	2SC3120	15	50	150	40 to 200	10	5	2400	10	2	17°/8	10	2	—	800	0.6	—	S-MINI
	2SC4245	15	50	100	40 to 200	10	5	2400	10	2	17°/8	10	2	—	800	0.6	—	USM
UHF OSC	2SC3121	15	50	150	60 to 320	3	8	1500	10	8	—	—	—	—	—	—	0.9	S-MINI
	2SC3547A	12	30	150	35 to 130	10	5	4000	10	10	—	—	—	—	—	—	1.05	S-MINI
	2SC4246	15	50	100	60 to 320	3	8	1500	10	8	—	—	—	—	—	—	0.9	USM
	2SC4247	12	30	100	35 to 130	10	5	4000	10	10	—	—	—	—	—	—	1.05	USM
PIF AMP	2SC3125	25	50	150	20 to 200	10	10	600	10	10	—	—	—	—	—	—	1.1	S-MINI
	2SC4253	25	50	100	20 to 200	10	10	600	10	10	—	—	—	—	—	—	1.1	USM

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2. FETs for TV Tuners

Application	Part Number	Maximum Ratings			Electrical Characteristics												Package Type
		V_{DS} (V_{GDO})	I_D	P_D	I_{DSS}			$\lvert Y_{fs} \rvert$ @1 kHz (typ.)				G_{PS} ($G_{CS^{\circ}}$)/NF ($NF_{CS^{\circ}}$) (typ.)					
						V_{DS}	V_{G1S}/ V_{G2S}		V_{DS}	I_D	V_{G2S}		V_{DS}	I_D	V_{G2S}	f	
		(V)	(mA)	(mW)	(mA)	(V)	(V)	(ms)	(V)	(mA)	(V)	(dB/dB)	(V)	(mA)	(V)	(MHz)	
VHF RF/MIX	3SK195	13.5	30	150	0 to 0.1	6	0/4	13	6	10	4	27/1.1	6	10	4	200	SMQ
	3SK225	13.5	30	150	0 to 0.1	6	0/4.5	21	6	10	4.5	22/2.0	6	10	4.5	500	SMQ
	3SK226	13.5	30	150	0 to 0.1	6	0/4.5	13	6	10	4.5	27/1.1	6	10	4.5	200	SMQ
	3SK257	13.5	30	100	0 to 0.1	6	0/4.5	21	6	10	4.5	22/2.0	6	10	4.5	500	USQ
	3SK258	13.5	30	100	0 to 0.1	6	0/4.5	13	6	10	4.5	27/1.1	6	10	4.5	200	USQ
	3SK260	15	30	100	3 to 14	6	0/3	27	6	10	3	24.5°/3.3°	6	—	—	200	USQ
	3SK292	12.5	30	150	0 to 0.1	6	0/4.5	23.5	6	10	4.5	21.5/1.8	6	10	4.5	500	SMQ
	3SK294	12.5	30	100	0 to 0.1	6	0/4.5	23.5	6	10	4.5	21.5/1.8	6	10	4.5	500	USQ
UHF RF/MIX	3SK199	13.5	30	150	0 to 0.1	6	0/4	21.5	6	10	4	19.5/1.9	6	10	4	800	SMQ
	3SK207	13.5	30	150	0 to 0.1	6	0/4.5	21.5	6	10	4.5	19.5/1.9	6	10	4.5	800	SMQ
	3SK232	12.5	30	150	0 to 0.1	6	0/4.5	21	6	10	4.5	20/1.5	6	10	4.5	800	SMQ
	3SK249	12.5	30	100	0 to 0.1	6	0/4.5	21	6	10	4.5	20/1.5	6	10	4.5	800	USQ
	3SK256	13.5	30	100	0 to 0.1	6	0/4.5	21.5	6	10	4.5	19.5/1.9	6	10	4.5	800	USQ
	3SK259	15	30	100	0 to 0.1	6	0/3	18.5	6	10	3	19/2.6	6	10	3	800	USQ
	3SK291	12.5	30	150	0 to 0.1	6	0/4.5	27	6	10	4.5	23/1.5	6	10	4.5	800	SMQ
	3SK293	12.5	30	150	0 to 0.1	6	0/4.5	27	6	10	4.5	23/1.5	6	10	4.5	800	SMQ

3. Transistors for the VHF-to-UHF Band

Application	Part Number	Maximum Ratings			Electrical Characteristics													Package Type
		V_{CEO}	I_C	P_C	C_{ob}	C_{re}	f_T (typ.)			$\lvert S_{21e}\rvert^2$ (typ.)				NF (typ.)				
								V_{CE}	I_C		V_{CE}	I_C	f		V_{CE}	I_C	f	
		(V)	(mA)	(mW)	(pF)	(pF)	(GHz)	(V)	(mA)	(dB)	(V)	(mA)	(GHz)	(dB)	(V)	(mA)	(GHz)	
VHF-to-UHF AMP	2SC2498	20	50	300	1.15	0.75	3.5	10	10	14.5	10	10	0.5	2.5	10	5	0.5	TO-92
	2SC5064	12	30	150	0.7	0.45	7	5	10	12	5	10	1	1.1	5	3	1	S-MINI
	2SC5065	12	30	100	0.7	0.45	7	5	10	12	5	10	1	1.1	5	3	1	USM
	2SC5066	12	30	100	0.7	0.45	7	5	10	12	5	10	1	1.1	5	3	1	SSM
	2SC5066FT	12	30	100	0.7	0.45	7	5	10	12	5	10	1	1.1	5	3	1	TESM
	2SC5084	12	80	150	1.1	0.7	7	10	20	11	10	20	1	1.1	10	5	1	S-MINI
	2SC5085	12	80	100	1.0	0.7	7	10	20	11	10	20	1	1.1	10	5	1	USM
	2SC5086	12	80	100	0.9	0.6	7	10	20	11	10	20	1	1.1	10	5	1	SSM
	2SC5086FT	12	80	100	0.9	0.6	7	10	20	11	10	20	1	1.1	10	5	1	TESM
	2SC5087	12	80	150	1.1	0.65	7	10	20	13	10	20	1	1.1	10	5	1	SMQ
	2SC5087R*	12	80	150	—	0.65	8	10	30	13.5	10	30	1	1.1	10	7	1	SMQ (R)
	2SC5088	12	80	100	1.1	0.65	7	10	20	13	10	20	1	1.1	10	5	1	USQ
	2SC5089	10	40	150	0.7	0.5	10	8	20	7.5	8	20	2	1.7	8	5	2	S-MINI
	2SC5090	10	40	100	0.7	0.5	10	8	20	7.5	8	20	2	1.7	8	5	2	USM
	2SC5091	10	40	100	0.7	0.5	10	8	20	7.5	8	20	2	1.7	8	5	2	SSM
	2SC5091FT	10	40	100	0.7	0.5	10	8	20	7.5	8	20	2	1.7	8	5	2	TESM
	2SC5092	10	40	150	0.7	0.45	10	8	20	9.5	8	20	2	1.8	8	5	2	SMQ
	2SC5093	10	40	100	0.65	0.45	10	8	20	9.5	8	20	2	1.8	8	5	2	USQ
	2SC5094	10	15	150	0.55	0.4	10	6	7	7	6	7	2	1.8	6	3	2	S-MINI
	2SC5095	10	15	100	0.5	0.4	10	6	7	7.5	6	7	2	1.8	6	3	2	USM
	2SC5096	10	15	100	0.45	0.4	10	6	7	8	6	7	2	1.8	6	3	2	SSM
	2SC5096FT	10	15	100	0.45	0.4	10	6	7	8	6	7	2	1.8	6	3	2	TESM
	2SC5097	10	15	150	0.5	0.35	10	6	7	10	6	7	2	1.8	6	3	2	SMQ
	2SC5098	10	15	100	0.5	0.34	10	6	7	10	6	7	2	1.8	6	3	2	USQ
	2SC5317FT	5	20	100	0.6	0.4	13	3	15	9	3	15	2	1.3	3	5	2	TESM
	2SC5319	5	20	100	0.6	0.4	16	3	15	11.5	3	15	2	1.3	3	5	2	USQ
	2SC5463	12	60	100	0.8	0.55	7	8	15	12	8	15	1	1.1	8	5	1	USM
	2SC5464	12	60	100	0.8	0.55	7	8	15	12	8	15	1	1.1	8	5	1	SSM
	2SC5464FT	12	60	100	0.8	0.55	7	8	15	12	8	15	1	1.1	8	5	1	TESM
	MT3S03A*	5	40	150	—	0.75	10	3	10	8	3	20	2	1.4	3	7	2	S-MINI
	MT3S03AFS	5	40	50	—	0.75	10	3	10	8.5	3	20	2	1.7	1	5	2	fSM
	MT3S03AS	5	40	100	—	0.75	10	3	10	8	3	20	2	1.4	3	7	2	SSM
	MT3S03AT	5	40	100	—	0.75	10	3	10	8	3	20	2	1.4	3	7	2	TESM
	MT3S03AU	5	40	100	—	0.75	10	3	10	8	3	20	2	1.4	3	7	2	USM
	MT3S04A*	5	40	150	—	0.75	7	3	7	13.5	3	20	1	1.2	3	7	1	SMQ
	MT3S04AFS	5	40	50	—	0.8	7	3	7	13	3	20	1	1.3	1	5	1	fSM
	MT3S04AS	5	40	100	—	0.8	7	3	7	12.5	3	20	1	1.2	3	7	1	SSM
	MT3S04AT	5	40	100	—	0.8	7	3	7	12.5	3	20	1	1.2	3	7	1	TESM
	MT3S04AU	5	40	100	—	0.8	7	3	7	12.5	3	20	1	1.2	3	7	1	USM
	MT3S05FS	5	40	50	—	0.9	4.5	1	5	12	3	20	1	1.4	1	5	1	fSM

*: New product

Application	Part Number	Maximum Ratings			Electrical Characteristics													Package Type
		V_{CEO}	I_C	P_C	C_{ob}	C_{re}	f_T (typ.)			$\|S_{21e}\|^2$ (typ.)				NF (typ.)				
								V_{CE}	I_C		V_{CE}	I_C	f		V_{CE}	I_C	f	
		(V)	(mA)	(mW)	(pF)	(pF)	(GHz)	(V)	(mA)	(dB)	(V)	(mA)	(GHz)	(dB)	(V)	(mA)	(GHz)	
VHF-to-UHF AMP	MT3S05T	5	40	100	—	0.9	4.5	1	5	11.5	3	20	1	1.4	1	5	1	TESM
	MT3S06FS	5	15	50	—	0.25	10	3	5	9.5	3	7	2	1.7	1	3	2	fSM
	MT3S06S	5	15	60	—	0.25	10	3	5	9.5	3	7	2	1.6	3	3	2	SSM
	MT3S06T	5	15	60	—	0.25	10	3	5	9.5	3	7	2	1.6	3	3	2	TESM
	MT3S06U	5	15	60	—	0.25	10	3	5	9.5	3	7	2	1.6	3	3	2	USM
	MT3S07FS	5	25	50	—	0.4	12	3	10	10	3	15	2	1.6	1	5	2	fSM
	MT3S07S	5	25	100	—	0.4	12	3	10	9.5	3	15	2	1.5	3	5	2	SSM
	MT3S07T	5	25	100	—	0.4	12	3	10	9.5	3	15	2	1.5	3	5	2	TESM
	MT3S07U	5	25	100	—	0.4	12	3	10	9.5	3	15	2	1.5	3	5	2	USM
	MT3S08T	8	40	100	—	0.55	4.5	1	5	13.5	3	20	1	1.4	1	5	1	TESM
	MT3S14FS	2.5	30	50	—	0.5	11	1	5	9	3	15	2	1.7	1	5	2	fSM
	MT3S14T	2.5	30	70	—	0.5	11	1	5	9	3	15	2	1.7	1	5	2	TESM
	MT3S16FS*	5	60	50	—	2.4	4	3	10	5.5	3	30	1	2.4	2	5	1	fSM
	MT3S16T*	5	60	100	—	2.4	4	3	10	5.5	3	30	1	2.4	2	5	1	TESM
	MT3S16U*	5	60	100	—	2.4	4	3	10	5.5	3	30	1	2.4	2	5	1	USM
	MT3S18T	8	20	100	—	0.4	6	1	5	14	3	15	1	1.4	1	5	1	TESM
	MT3S18FS*	8	20	100	—	0.4	6	1	5	14	3	15	1	1.4	1	5	1	fSM
	MT3S35FS	4.5	24	100	0.30	0.15	20	3	10	13	3	10	2	1.4	3	2	2	fSM
	MT3S35T	4.5	24	100	0.46	0.21	20	3	10	13	3	10	2	1.4	3	3	2	TESM
	MT3S36FS	4.5	36	100	0.37	0.21	19	3	15	12.5	3	15	2	1.3	3	3	2	fSM
	MT3S36T	4.5	36	100	0.55	0.26	19	3	15	12.5	3	15	2	1.3	3	3	2	TESM
	MT3S37FS	4.5	50	100	0.49	0.30	19	3	20	12	3	20	2	1.2	3	3	2	fSM
	MT3S37T	4.5	50	100	0.66	0.35	19	3	20	12	3	20	2	1.2	3	3	2	TESM
	MT3S41FS	4.5	80	100	0.72	0.46	15	3	20	10	3	20	2	1.2	3	5	2	fSM
	MT3S41T	4.5	80	100	0.90	0.55	15	3	20	10	3	20	2	1.2	3	5	2	TESM
	MT3S45FS	4.5	30	100	0.53	0.28	18	3	20	12.5	3	20	2	1.1	3	6	2	fSM
	MT3S45T	4.5	30	100	0.66	0.33	18	3	20	12.5	3	20	2	1.1	3	6	2	TESM
	MT3S106FS*	13	80	100	—	0.5	8.5	1	10	8	1	10	2	1.2	1	10	2	fSM
	MT3S107FS*	8.5	20	100	0.44	0.19	16.5	1	10	13	3	10	2	0.85	1	5	1	fSM
	MT4S03A	5	40	150	—	0.7	10	3	10	9	3	20	2	1.4	3	7	2	SMQ
	MT4S03AU	5	40	100	—	0.7	10	3	10	9	3	20	2	1.4	3	7	2	USQ
	MT4S04A	5	40	150	—	0.75	7	3	7	13.5	3	20	1	1.2	3	7	1	SMQ
	MT4S04AU	5	40	100	—	0.75	7	3	7	13.5	3	20	1	1.2	3	7	1	USQ
	MT4S06	5	15	60	—	0.23	10	3	5	11.5	3	7	2	1.6	3	3	2	SMQ
	MT4S06U	5	15	60	—	0.23	10	3	5	11.5	3	7	2	1.6	3	3	2	USQ
	MT4S07	5	25	150	—	0.4	12	3	10	10.5	3	15	2	1.5	3	5	2	SMQ
	MT4S07U*	5	25	100	—	0.4	12	3	10	10.5	3	15	2	1.5	3	5	2	USQ
	MT4S100T	3	15	45	0.41	0.14	23	2	10	17	2	10	2	0.72	2	5	2	TESQ
	MT4S100U	3.0	15	45	0.41	0.14	22	2	10	16	2	10	2	0.72	2	5	2	USQ
	MT4S101T	3	10	30	0.34	0.1	23	2	7	17	2	7	2	0.8	2	5	2	TESQ
	MT4S101U	3.0	10	30	0.34	0.10	21	2	7	16	2	7	2	0.8	2	5	2	USQ
	MT4S102T	3	20	60	0.43	0.17	25	2	15	16	2	15	2	0.58	2	10	2	USQ
	MT4S102U	3	20	60	0.43	0.17	24	2	15	15	2	15	2	0.58	2	10	2	TESQ
	MT4S104T	3	10	30	0.26	0.09	25	2	7	18	2	7	2	0.67	2	5	2	USQ
	MT4S104U	3	10	30	0.26	0.09	23	2	7	17	2	7	2	0.67	2	5	5	TESQ
	MT4S200U*	8	35	100	0.25	0.074	30	3	15	17.5	3	15	2	1.7	3	5	2	USQ
	MT4S32U	4.5	15	67.5	0.4	0.2	16	3	10	13.5	3	10	2	1.4	3	3	5	USQ

*: New product

Application	Part Number	Maximum Ratings			Electrical Characteristics														Package Type
		V_{CEO}	I_C	P_C	C_{ob}	C_{re}	f_T (typ.)			$\|S_{21e}\|^2$ (typ.)				NF (typ.)					
								V_{CE}	I_C		V_{CE}	I_C	f		V_{CE}	I_C	f		
		(V)	(mA)	(mW)	(pF)	(pF)	(GHz)	(V)	(mA)	(dB)	(V)	(mA)	(GHz)	(dB)	(V)	(mA)	(GHz)		
VHF-to-UHF OSC	2SC3547A	12	30	150	1.05	—	4	10	10	—	—	—	—	—	—	—	—	S-MINI
	2SC4247	12	30	100	1.05	—	4	10	10	—	—	—	—	—	—	—	—	USM
	2SC5106	10	30	150	0.75	0.5	6	5	5	11	5	5	1	—	—	—	—	S-MINI
	2SC5107	10	30	100	0.75	0.5	6	5	5	11	5	5	1	—	—	—	—	USM
	2SC5108	10	30	100	0.7	0.5	6	5	5	11	5	5	1	—	—	—	—	SSM
	2SC5108FT	10	30	100	0.7	0.5	6	5	5	11	5	5	1	—	—	—	—	TESM
	2SC5109	10	60	150	0.9	0.7	5	5	5	10	5	5	1	—	—	—	—	S-MINI
	2SC5110	10	60	100	0.9	0.7	5	5	5	10	5	5	1	—	—	—	—	USM
	2SC5111	10	60	100	0.9	0.7	5	5	5	10	5	5	1	—	—	—	—	SSM
	2SC5111FT	10	60	100	0.9	0.7	5	5	5	10	5	5	1	—	—	—	—	TESM
	MT3S03A*	5	40	150	—	0.75	10	3	10	8	3	20	2	1.4	3	7	2	S-MINI
	MT3S03AFS	5	40	50	—	0.75	10	3	10	8.5	3	20	2	1.7	1	5	2	fSM
	MT3S03AS*	5	40	100	—	0.75	10	3	10	8	3	20	2	1.4	3	7	2	SSM
	MT3S03AT*	5	40	100	—	0.75	10	3	10	8	3	20	2	1.4	3	7	2	TESM
	MT3S03AU*	5	40	100	—	0.7	10	3	10	9	3	20	2	1.4	3	7	2	USQ
	MT3S04A*	5	40	150	—	0.8	7	3	7	12.5	3	20	1	1.2	3	7	1	S-MINI
	MT3S04AFS	5	40	50	—	0.8	7	3	7	13	3	20	1	1.3	1	5	1	fSM
	MT3S04AS*	5	40	100	—	0.8	7	3	7	12.5	3	20	1	1.2	3	7	1	SSM
	MT3S04AT*	5	40	100	—	0.8	7	3	7	12.5	3	20	1	1.2	3	7	1	TESM
	MT3S04AU*	5	4	100	—	0.8	7	3	7	12.5	3	20	1	1.2	3	7	1	USM
	MT3S05FS	5	40	50	—	0.9	4.5	1	5	12	3	20	1	1.4	1	5	1	fSM
	MT3S05T*	5	40	100	—	0.9	4.5	1	5	8.5	1	5	1	1.4	1	5	1	TESM
	MT3S08FS	8	40	50	—	0.55	4.5	1	5	14	3	20	1	1.4	1	5	1	fSM
	MT3S08T*	8	40	100	—	0.55	4.5	1	5	10.5	1	5	1	1.4	1	5	1	TESM
	MT3S106FS*	13	80	100	—	0.5	8.5	1	10	8	1	10	2	1.2	1	10	2	fSM
	MT3S108FS*	4.5	25	100	0.41	0.3	13	1	10	11	3	10	2	0.85	1	7	2	fSM
	MT3S109FS*	13	80	100	—	0.75	7.1	1	10	8.2	3	20	2	1.35	1	15	2	fSM
	MT3S110FS*	13	80	100	—	0.6	7.5	1	10	9	3	20	2	1.3	1	15	2	fSM
	MT3S11FS	6	40	50	—	0.65	6	1	5	6.5	3	20	2	2.4	1	5	2	fSM
	MT3S11T	6	40	100	—	0.65	6	1	5	6.5	3	20	2	2.4	1	5	2	TESM
	MT3S12T	6	40	100	—	0.7	7	1	5	7	3	20	2	1.7	1	5	2	TESM
	MT3S18T	8	20	100	—	0.4	6	1	5	14	3	15	1	1.4	1	5	1	TESM
	MT4S03A*	5	40	150	—	0.7	10	3	10	9	3	20	2	1.4	3	7	2	SMQ
	MT4S03AU*	5	40	100	—	0.7	10	3	10	9	3	20	2	1.4	3	7	2	USQ
	MT4S04A*	5	40	150	—	0.75	7	3	7	13.5	3	20	1	1.2	3	7	1	SMQ
	MT4S04AU*	5	40	100	—	0.75	7	3	7	13.5	3	20	1	1.2	3	7	1	USQ

*: New product

4. Transistors for AM and FM Tuners

Application	Part Number	Maximum Ratings			Electrical Characteristics							Package Type
		V_{CEO} (V)	I_C (mA)	P_C (mW)	h_{FE}	V_{CE} (V)	I_C (mA)	f_T Typ. (min) (MHz)	V_{CE} (V)	I_C (mA)	C_{re} (C_{ob}) (pF)	
FM RF, MIX/OSC	2SC1923	30	20	100	40 to 200	6	1	550	6	1	0.7	TO-92
	2SC2668	30	20	100	40 to 200	6	1	550	6	1	0.7	MINI
	2SC2714	30	20	100	40 to 200	6	1	550	6	1	0.7	S-MINI
	2SC4215	30	20	100	40 to 200	6	1	550	6	1	0.7	USM
	2SC4915	30	20	100	40 to 200	6	1	550	6	1	0.7	SSM
FM OSC	2SC2995	30	50	200	40 to 240	6	1	350	6	1	0.9	MINI
	2SC2996	30	50	150	40 to 240	6	1	350	6	1	0.9	S-MINI
FM IF/AM CONV, IF	2SC380TM	30	50	300	40 to 240	12	2	(100)	10	1	(2.0)	TO-92
	2SC2669	30	50	200	40 to 240	12	2	(100)	10	1	(2.0)	MINI
	2SC2715	30	50	150	40 to 240	12	2	(100)	10	1	(2.0)	S-MINI
AM RF, CONV	2SC941TM	30	100	400	40 to 240	12	2	(80)	10	2	2.2	TO-92
	2SC2670	30	100	200	40 to 240	12	2	(80)	10	2	2.2	MINI
	2SC2716	30	100	150	40 to 240	12	2	(80)	10	2	2.2	S-MINI
AM CONV, IF	2SC1815	50	150	400	70 to 700	6	2	(80)	10	1	(2.0)	TO-92
	2SC2458	50	150	200	70 to 700	6	2	(80)	10	1	(2.0)	MINI
	2SC2712	50	150	150	70 to 700	6	2	(80)	10	1	(2.0)	S-MINI
	2SC4116	50	150	100	70 to 700	6	2	(80)	10	1	(2.0)	USM

5. FETs for AM and FM Tuners

Application	Part Number	Maximum Ratings			Electrical Characteristics												Package Type
		V_{DS} *V_{GDS} (V_{GDO}) (V)	I_D (I_C) (mA)	P_D (mW)	I_{DSS} (mA)	V_{DS} (V)	V_{G1S}/ V_{G2S} (V)	$\lvert Y_{fs} \rvert$ @1 kHz (typ.) (ms)	V_{DS} (V)	I_D (mA)	V_{G2S} V_{GS} (V)	G_{rs} ($G_{CS°}$)/NF ($NF_{CS°}$) (typ.) (dB/dB)	V_{DS} (V)	I_D (mA)	V_{G2S} (V_{GS}) (V)	f (MHz)	
FM RF, MIX	3SK195	13.5	30	150	0 to 0.1	6	0/4	13	6	10	4	27/1.1	6	—	4	200	SMQ
	3SK225	13.5	30	150	0 to 0.1	6	0/4.5	21	6	10	4.5	22/2.0	6	10	4.5	500	SMQ
	3SK226	13.5	30	150	0 to 0.1	6	0/4.5	13	6	10	4.5	27/1.1	6	10	4.5	200	SMQ
	3SK257	13.5	30	100	0 to 0.1	6	0/4.5	21	6	10	4.5	22/2.0	6	10	4.5	500	USQ
	3SK258	13.5	30	100	0 to 0.1	6	0/4.5	13	6	10	4.5	27/1.1	6	10	4.5	200	USQ
FM RF	2SK241	20	30	200	1.5 to 14	10	0	10	10	—	(0)	28/1.7	10	—	(0)	100	MINI
	2SK302	20	30	150	1.5 to 14	10	0	10	10	—	(0)	28/1.7	10	—	(0)	100	S-MINI
	2SK882	20	30	100	3 to 14	10	0	10	10	—	(0)	28/1.7	10	—	(0)	100	USM
	2SK161	(−18)	(10)	200	1 to 10	10	0	9	10	—	(0)	18/2.5	10	—	(0)	100	MINI
	2SK211	(−18)	(10)	150	1 to 10	10	0	9	10	—	(0)	18/2.5	10	—	(0)	100	S-MINI
	2SK881	(−18)	(10)	100	1 to 10	10	0	9	10	—	(0)	18/2.5	10	—	(0)	100	USM
	2SK1771	12.5	30	150	0 to 0.1	8	0	15	8	10	—	23/1.0	8	16	—	100	SMQ
FM RF, OSC	2SK192A	(−18)	(10)	200	3 to 24	10	0	7	10	—	(0)	24/1.8	10	—	(0)	100	MINI
	2SK210	(−18)	(10)	100	3 to 24	10	0	7	10	—	(0)	24/1.8	10	—	(0)	100	S-MINI
AM RF	2SK709	*−20	(10)	300	6 to 32	5	0	25	5	—	(0)	—/0.5	5	1	Rg 1 kΩ	1 kHz	TO-92
	2SK710	*−20	(10)	200	6 to 32	5	0	25	5	—	(0)	—/0.5	5	1	Rg 1 kΩ	1 kHz	MINI
	2SK711	*−20	(10)	150	6 to 32	5	0	25	5	—	(0)	—	—	—	—	—	S-MINI
	2SK1875	*−20	(10)	100	6 to 32	5	0	25	5	—	(0)	—	—	—	—	—	USM

6. Dual-Chip Transistors for AM Tuners

Application	Part Number	V_{GDS} (V)	I_G (mA)	V_{CEO} (V)	I_C (mA)	P_T (mW)	I_{DSS} (mA)	V_{DS} (V)	V_{GS} (V)	|Yfs| Typ. (ms)	V_{DS} (V)	V_{GS} (V)	h_{FE}	V_{CE} (V)	I_C (mA)	Contents	Package Type
AM RF	HN3G01J	−20	10	50	150	200	6 to 32	5	0	25	5	0	120 to 400	6	2	2SK711 + 2SC2712	SMV

Package type: SMV (SSOP5-P-0.95)

7. Dual-Chip Transistors for the VHF-to-UHF Band

Application	Part Number	tr	V_{CEO} (V)	I_C (mA)	PC▲ (mW)	h_{FE}	h_{FE} V_{CE} (V)	h_{FE} I_C (mA)	f_T Typ. (GHz)	f_T V_{CE} (V)	f_T I_C (mA)	NF Typ. (dB)	NF V_{CE} (V)	NF I_C (mA)	NF f (GHz)	Component Devices	Package Type
VHF-to-UHF Low-Noise Amp	MT6L03AE		5	40	100	80 to 160	1	5	10	3	10	1.4	3	7	2	MT3S03AS × 2	ES6
	MT6L03AT		5	40	200	80 to 160	1	5	10	3	10	1.4	3	7	2	MT3S03AS × 2	TU6
	MT6L04AE		5	40	100	80 to 160	1	5	7	3	7	1.2	3	7	1	MT3S04AS × 2	ES6
	MT6L04AT		5	40	200	80 to 160	1	5	7	3	7	1.2	3	7	1	MT3S04AS × 2	TU6
VHF-to-UHF Buffer + OSC	MT6C03AE		5	40	100	80 to 160	1	5	10	3	10	1.4	3	7	2	MT3S03AS × 2	ES6
	MT6C04AE		5	40	100	80 to 160	1	5	7	3	7	1.2	3	7	1	MT3S04AS × 2	ES6
	MT6L05FS*		5	40	100	80 to 140	1	5	4.5	1	5	1.4	1	5	1	MT3S05FS × 2	fSM
	MT6L11FS*		6	40	100	100 to 160	1	5	6	1	5	2.4	1	5	2	MT3S11FS × 2	fSM
	MT6L53E	Q1	5	15	100	70 to 140	1	5	10	3	5	1.6	3	3	2	MT3S06S	ES6
		Q2	5	40		80 to 140	1	5	4.5	1	5	1.4	1	5	1	MT3S05T	
	MT6L54E	Q1	5	15	100	70 to 140	1	5	10	3	5	1.6	3	3	2	MT3S06S	ES6
		Q2	8	40		80 to 140	1	5	4.5	1	5	1.4	1	5	1	MT3S08T	
	MT6L55E	Q1	5	25	150	70 to 140	1	5	12	3	10	1.5	3	5	2	MT3S07S	ES6
		Q2	5	40		80 to 140	1	5	4.5	1	5	1.4	1	5	1	MT3S05T	
	MT6L55FS	Q1	5	25	50	70 to 140	1	5	12	3	10	1.5	1	5	2	*MT3S07FS	fS6
		Q2	5	40		80 to 140	1	5	4.5	1	5	1.4	1	5	1	*MT3S05FS	
	MT6L56E	Q1	5	25	150	70 to 140	1	5	12	3	10	1.5	3	5	2	MT3S07S	ES6
		Q2	8	40		80 to 140	1	5	4.5	1	5	1.4	1	5	1	MT3S08T	
	MT6L57AE	Q1	5	15	100	70 to 140	1	5	10	3	5	1.6	3	3	2	MT3S06S	ES6
		Q2	5	40		80 to 160	1	5	7	3	7	1.2	3	7	1	MT3S04AS	
	MT6L58AE	Q1	5	15	100	70 to 140	1	5	10	3	5	1.6	3	3	2	MT3S06S	ES6
		Q2	5	40		80 to 160	1	5	10	3	10	1.4	3	7	2	MT3S03AS	
	MT6L61AE	Q1	5	25	100	70 to 140	1	5	12	3	10	1.5	3	5	2	MT3S07S	ES6
		Q2	5	40		80 to 160	1	5	7	3	7	1.2	3	7	1	MT3S03AS	
	MT6L62AE	Q1	5	25	100	70 to 140	1	5	12	3	10	1.5	3	5	2	MT3S07S	ES6
		Q2	5	40		80 to 160	1	5	10	3	10	1.4	3	7	2	MT3S03AS	
	MT6L63FS	Q1	5	25	50	70 to 140	1	5	12	3	10	1.5	1	5	2	MT3S07FS	fS6
		Q2	6	40		100 to 160	1	5	6	1	5	2.4	1	5	2	MT3S11FS	
	MT6L64FS	Q1	4.5	24	50	70 to 140	3	10	20	3	10	1.4	3	2	2	MT3S35FS	fS6
		Q2	6	40		100 to 160	1	5	6	1	5	2.4	1	5	2	MT3S11FS	

▲: Total PC

*: New product

Application	Part Number	tr	V_{CEO} (V)	I_C (mA)	PC▲ (mW)	h_{FE}	h_{FE} V_{CE} (V)	h_{FE} I_C (mA)	f_T Typ. (GHz)	f_T V_{CE} (V)	f_T I_C (mA)	NF Typ. (dB)	NF V_{CE} (V)	NF I_C (mA)	NF f (GHz)	Component Devices	Package Type
VHF-to-UHF Buffer + OSC	MT6L65FS	Q1	4.5	36	50	70 to 140	3	10	20	3	10	1.3	3	2	2	MT3S36FS	fS6
		Q2	6	40		100 to 160	1	5	6	1	5	2.4	1	5	2	MT3S11FS	
	MT6L66FS	Q1	4.5	36	50	70 to 140	3	10	20	3	10	1.3	3	2	2	MT3S36FS	fS6
		Q2	6	40		100 to 160	1	5	7	1	5	1.7	1	5	2	MT3S12FS	
	MT6L67FS	Q1	4.5	50	50	70 to 140	3	20	19	3	20	1.2	3	3	2	MT3S37FS	fS6
		Q2	6	40		100 to 160	1	5	7	1	5	1.7	1	5	2	MT3S12FS	
	MT6L68FS	Q1	5	15	50	70 to 140	1	5	10	3	5	1.7	1	3	2	MT3S06FS	fS6
		Q2	6	40		100 to 160	1	5	6	1	5	2.4	1	5	2	MT3S11FS	
	MT6L71FS*	Q1	5	25	50	70 to 140	1	5	12	3	10	1.5	3	5	2	MT3S07FS	fS6
		Q2	6	25		100 to 160	1	5	6	1	5	2.4	1	5	2	MT3S11AFS	
	MT6L72FS*	Q1	4.5	36	50	70 to 140	3	10	19	3	15	1.3	3	3	2	MT3S36FS	fS6
		Q2	6	40		100 to 160	1	5	6	1	5	2.4	1	5	2	MT3S11AFS	
	MT6L73FS*	Q1	5	25	100	70 to 140	1	5	12	3	10	1.5	1	5	2	MT3S07FS	fS6
		Q2	6	50		75 to 125	1	5	7	1	10	1.35	1	15	2	MT3S109FS	
	MT6L74FS*	Q1	5	25	100	70 to 140	1	5	12	3	10	1.5	1	5	2	MT3S07FS	fS6
		Q2	6	80		75 to 125	1	5	7.5	1	10	1.35	1	15	2	MT3S110FS	
	MT6L75FS*	Q1	5	25	100	70 to 140	1	5	12	3	10	1.5	1	5	2	MT3S07FS	fS6
		Q2	6	80		110 to 160	1	5	8.5	1	10	1.2	1	10	2	MT3S106FS	
	MT6L76FS*	Q1	5	15	100	70 to 140	1	5	10	3	5	1.7	1	3	2	MT3S06FS	fS6
		Q2	6	80		110 to 160	1	5	8.5	1	10	1.2	1	10	2	MT3S106FS	
	MT6L77FS*	Q1	6	40	100	70 to 140	1	5	6	1	5	2.4	1	5	2	MT3S11FS	fS6
		Q2	6	80		110 to 160	1	5	8.5	1	10	1.2	1	10	2	MT3S106FS	
	MT6L78FS*	Q1	6	40	5	100 to 160	1	5	6	1	5	2.4	1	5	2	MT3S11FS	fS6
		Q2	6	40		100 to 160	1	5	6	1	5	2.4	1	5	2	MT3S11AFS	

▲: Total PC

*: New product

8. Cell Packs for the VHF-to-UHF Band

Application	Part Number	I_{CC}		$\vert S_{21}\vert^2$ Typ.			NF Typ.			BW Typ.		PO Typ. (PoldB)				Package Type
		(mA)	V_{CC} (V)	(dB)	V_{CC} (V)	f (MHz)	(dB)	V_{CC} (V)	f (MHz)	(GHz)	V_{CC} (V)	(dBmW)	V_{CC} (V)	f (MHz)	Pi (dBmW)	
VHF-to-UHF wide-band amp	TA4001F	18	5	12.5	5	500	5.2	5	500	2.4	5	2	5	500	0	SMQ
VHF-to-UHF wide-band amp	TA4002F	14	5	23	5	500	4.7	5	500	1.3	5	5	5	500	0	SMQ
VHF-to-UHF wide-band amp	TA4004F	3.1	2	10.5	2	500	4.2	2	500	1.2	2	0	2	500	0	SMV
UHF wide-band amp	TA4011FU	3.5	2	10	2	1500	6.5	2	1500	2.4	2	(−6)	2	1500	—	USV
UHF wide-band amp	TA4012FU	6.5	2	12	2	1500	6	2	1500	2.0	2	(0)	2	1500	—	USV
UHF wide-band amp	TA4011AFE	3.5	2	10	2	1500	6.5	2	1500	2.4	2	(−6)	2	1500	—	ESV
UHF wide-band amp	TA4012AFE	6.5	2	12	2	1500	6	2	1500	2.0	2	(0)	2	1500	—	ESV
UHF wide-band amp	TA4016AFE	6	2	19	2	1500	4.5	2	1500	3.2	2	(−7)	2	1500	—	ES6
VHF wide-band amp	TA4017FT	19	5	13	5	45	3	5	45	1	5	2	5	45	−10	TU6
VHF gain control amp	TA4018F	28	5	11	5	45	11.5	5	45	—	—	−9	5	45	−20	SM8
VHF wide-band amp	TA4019F	35	5	30	5	45	8	5	45	0.3	5	−5	5	45	−35	SM8

Application	Part Number	I_{CC} Typ. (mA)	P_D (mW)	G_{MIX}/NF_{MIX} (dB/dB)	V_{CC} (V)	f_{RF} (MHz)	f_{LO} (MHz)	f_{IF} (MHz)	Package Type
VHF-to-UHF DBM	TA4101F	5.7	300*	−3.5/9.0	5	800	860	60	SM8
VHF-to-UHF DBM	TA4107F	29.5	370*	−0.5/12	4.5	1000	950	50	SM8

*: Mounted on a 2.5 cm^2 × 1.6 t glass epoxy board

Package type: SMV (SSOP5-P-0.95), SM6 (SSOP6-P-0.95), SM8 (SSOP8-P-0.65), USV (SSOP5-P-0.65)

Application	Part Number	I_{CC} Typ. (mA)	V_{CC} (V)	f (MHz)*	V_{OUT} (Vpp)*	F_S (ppm)*	Package Type
TCXO	TA4014FT	1.2	3	10 to 30	1.2	±0.1	TU6
	TA4014FE	1.2	3	10 to 30	1.2	±0.1	ES6
	TA4014FC	1.2	3	10 to 30	1.2	±0.1	CS6
	TA4015FT	1.3	3	10 to 30	1.2	±0.1	TU6
	TA4015FE	1.3	3	10 to 30	1.2	±0.1	ES6

*: Reference values: f = oscillating frequency range, F_S = supply voltage fluctuation

9. SiGe Cell Packs

Part Number	Package	Circuit	Application	Characteristics (Typ.)
TA4020FT	TESQ	Linear amp	GPS UHF low-noise amp	$\|S_{21e}\|^2$ = 15dB, NF = 0.95dB, IIP_3 = −9.5dBmW @V_{CC} = 3 V, f = 1.5 GHz
TA4500F	QS16	Low-noise amp + down-conversion MIX	PHS Digital cordless phone	G_{LNA} = 17.5dB, G_{MIX} = 5dB, IIP_{LNA} = −7.5dBmW, IIP_{3MIX} = 7.0dBmW, 1/2 IFR_{MIX} = 45dB @V_{CC} = 3 V, f = 1.9 GHz

10. GaAs Cell Packs

Product List

	TU6	UF6	sES6	CST6B
Low-power switch	TG2210FT TG2211AFT*	—	TG2213S TG2214S	TG2217CTB
Medium-power switch	—	TG2216TU	—	—

*: Built-in inverter

Main Characteristics

Part Number	Package	Circuit	Application	Characteristics
TG2210FT	TU6	SPDT	General-Purpose, Bluetooth Class 2/3	Loss = 0.4dB, ISL = 30dB, Pi1dB > 18dBmW
TG2211AFT*	TU6	SPDT	General-Purpose, Bluetooth Class 2/3	Loss = 0.5dB,ISL = 30dB, Pi1dB = 17dBmW
TG2213S	sES6	SPDT	General-Purpose, Bluetooth Class 2/3	Loss = 0.35dB, ISL = 24dB, Pi1dB = 17dBmW
TG2214S	sES6	SPDT	General-Purpose, Bluetooth Class 2/3	Loss = 0.35dB, ISL = 24dB, Pi1dB = 17dBmW Opposite switch connection to the TG2213S
TG2216TU	UF6	SPDT	Wireless LAN, PHS, Bluetooth	Loss = 0.5dB, ISL = 25dB, Pi1dB = 28dBmW
TG2217CTB	CST6B	SPDT	General-Purpose	Loss = 0.45dB, ISL = 22dB, Pi1dB = 14dBmW @f = 2.5 GHz

*: Built-in inverter

1.9 GHz Band TX Front-End IC

Part Number	Package	Circuit	Application	Characteristics (Typ.)
TG2403CT	CST20	GaAs linear power amp + SPDT switch	PHS Digital cordless phone	PA: $G_P \geq$ 36dB, Itotal $\leq$ 180 mA @f = 1.92 GHz, P_o = 20.5dBmW, V_{gg} = per rank (0 to 2 V) SW: $Loss_{RX}$ = 0.5dB ISL_{TX} = 25dB ISL_{RX} = 15dB @f = 1.92 GHz, V_C = 0 V/3 V

11. Silicon Germanium Transistors

- New silicon germanium transistor
- Compact TESQ package in addition to the USQ package
- Lower noise figure and higher transition frequency

High-Frequency Characteristics

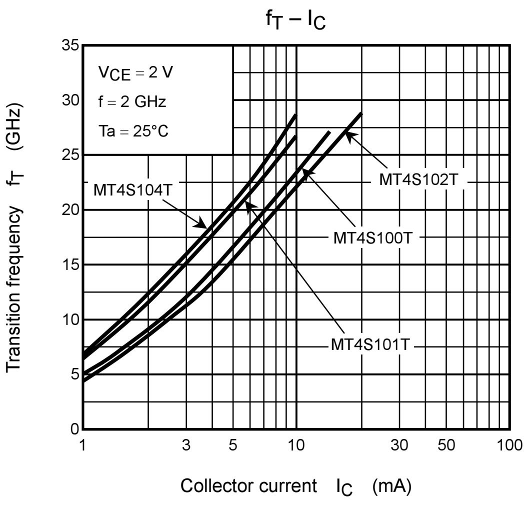
Characteristic	f_T (Typ.)			$\|S_{21e}\|^2$ (Typ.)				NF (Typ.)			
Part Number	(GHz)	V_{CE} (V)	I_C (mA)	(dB)	V_{CE} (V)	I_C (mA)	f (GHz)	(dB)	V_{CE} (V)	I_C (mA)	f (GHz)
MT4S101U	21	2	7	16	2	7	2	0.8	2	5	2
MT4S101T	23			17							
MT4S100U	22	2	10	16	2	10	2	0.72	2	5	2
MT4S100T	23			17							
MT4S102U	24	2	15	15	2	15	2	0.58	2	10	2
MT4S102T	25			16							
MT4S104U	23	2	7	17	2	7	2	0.67	2	5	5
MT4S104T	25			18							
MT4S200U*	30	3	20	17.5	3	20	2	0.8	3	5	20

*: New product

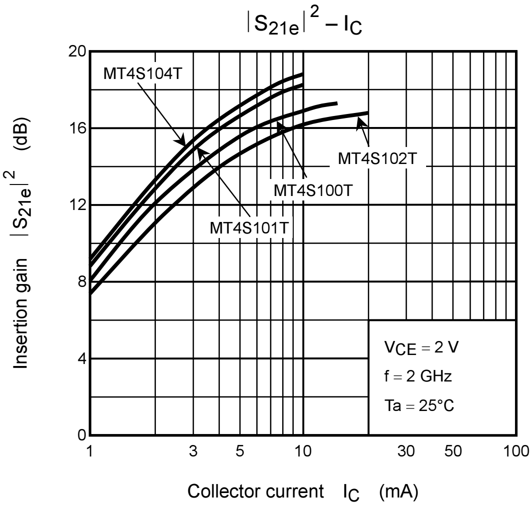
Product List

Package Type	USQ	TESQ
f_T = 21 GHz low-voltage operating device	MT4S101U	MT4S101T
f_T = 22 GHz low-voltage operating device	MT4S100U	MT4S100T
f_T = 25 GHz low-voltage operating device	MT4S102U	MT4S102T
	MT4S104U	MT4S104T
f_T = 30 GHz low-voltage operating device	MT4S200U*	—

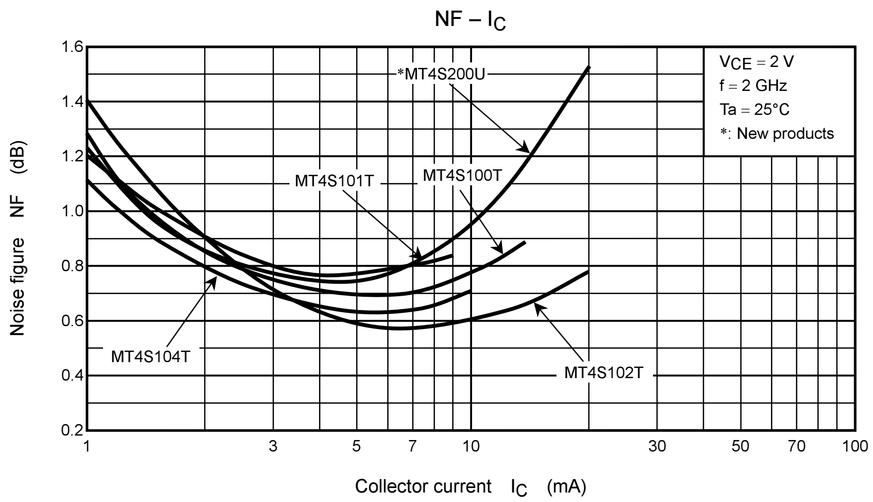
*: New product



f_T – I_C
V_{CE} = 2 V
f = 2 GHz
Ta = 25°C
MT4S104T
MT4S102T
MT4S100T
MT4S101T
Transition frequency f_T (GHz)
Collector current I_C (mA)



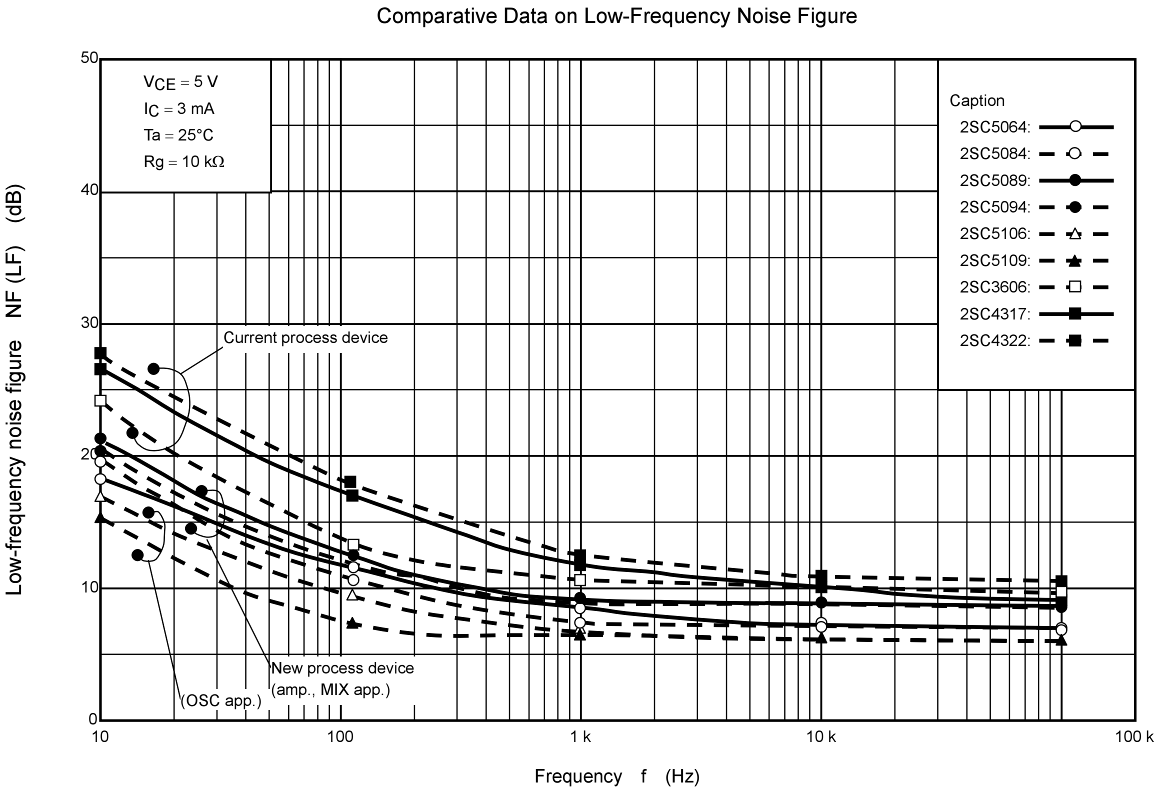
$|S_{21e}|^2$ – I_C
MT4S104T
MT4S102T
MT4S100T
MT4S101T
V_{CE} = 2 V
f = 2 GHz
Ta = 25°C
Insertion gain $|S_{21e}|^2$ (dB)
Collector current I_C (mA)



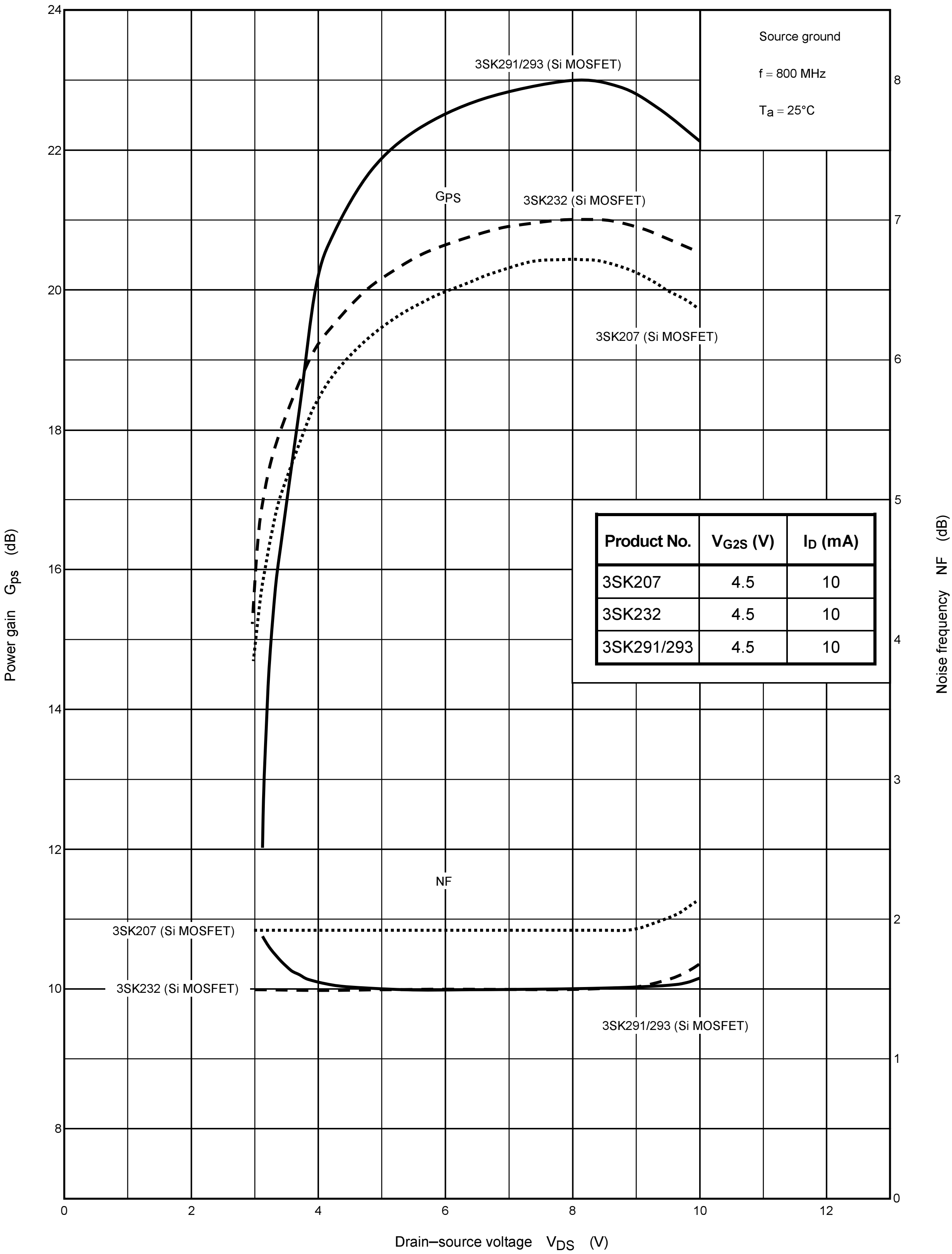
NF – I_C
V_{CE} = 2 V
f = 2 GHz
Ta = 25°C
*: New products
*MT4S200U
MT4S101T
MT4S100T
MT4S104T
MT4S102T
Noise figure NF (dB)
Collector current I_C (mA)

12. Low-Frequency Noise Characteristics of Microwave Transistors

RF transistors

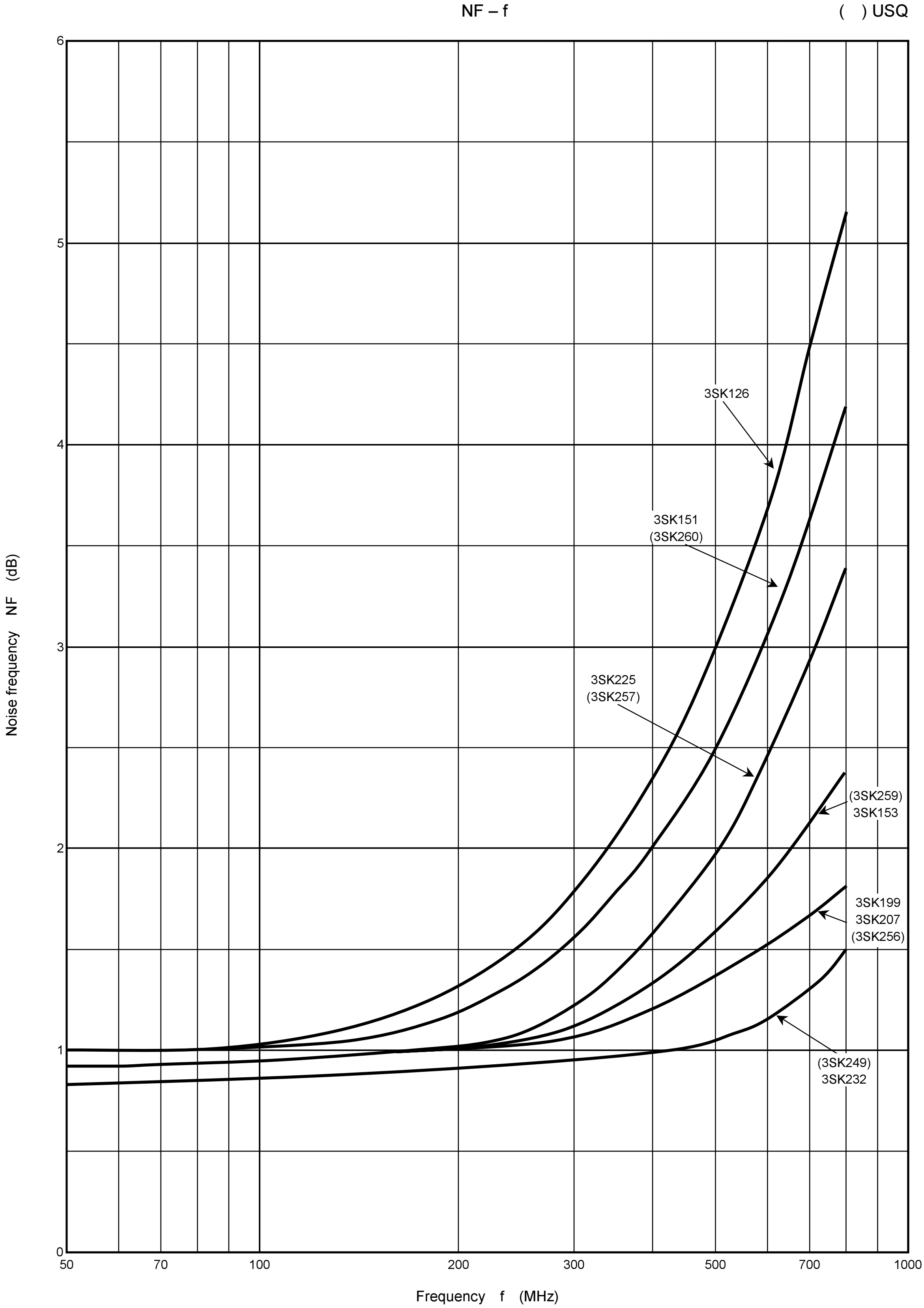


13. G_{PS}, NF – V_{DS} Characteristics of Dual-Gate FETs



Product No.	V_{G2S} (V)	I_D (mA)
3SK207	4.5	10
3SK232	4.5	10
3SK291/293	4.5	10

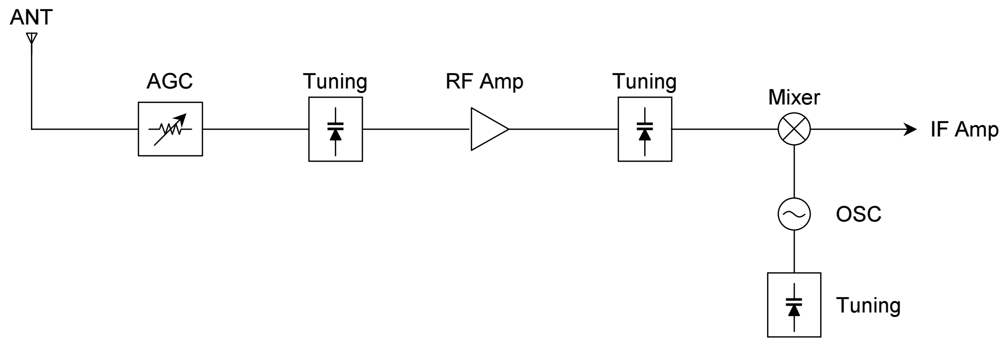
14. Noise Figure–Frequency Characteristics of Dual-Gate FETs



[4] Block Diagrams for Suggested Applications

[4] Block Diagrams for Suggested Applications

1. Radio-Frequency Devices for AM Tuners



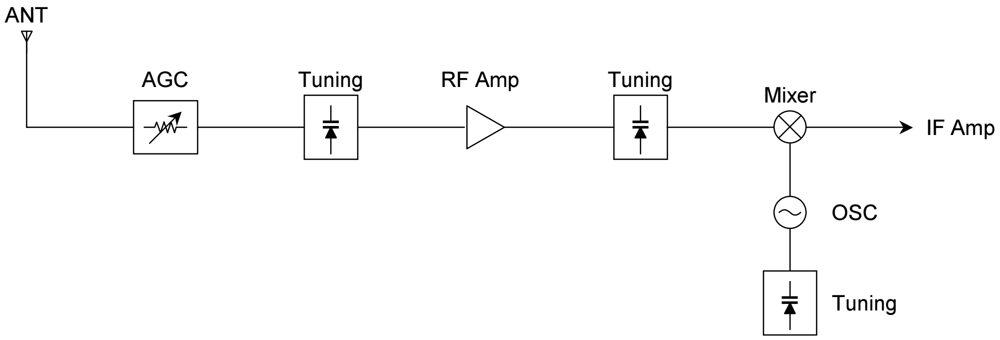
Application	Type		Package	Part Number
AGC	PIN diode	Single	S-MINI	1SV128
			USC	1SV271 1SV307
			ESC	1SV308 JDP2S01E JDP2S04E
		Dual	S-MINI	1SV172
			SMQ	1SV237
			USM	1SV252
			USQ	1SV312 JDP4P02U

Application	Type	Package	Part Number
AGC	Bipolar transistor	MINI	2SC2458
		S-MINI	2SC2712
RF Amp	JFET	TO-92	2SK709
		MINI	2SK710
		S-MINI	2SK711
		USM	2SK1875
	Dual transistor	SMV	HN3G01J

Application	Type	Package	Part Number
Tuning	Tuning varicap diode	MINI	1SV102 1SV149-B
		FM8	HN1V01H HN1V02H HN2V02H

Application	Type	Package	Part Number
Mixer	Bipolar transistor	TO-92	2SC380TM 2SC941TM
		MINI	2SC2669 2SC2670
		S-MINI	2SC2715 2SC2716

2. Radio-Frequency Devices for FM Tuners



Application	Type		Package	Part Number
AGC	PIN diode	Single	S-MINI	1SV128
			USC	1SV271 1SV307
			ESC	1SV308 JDP2S01E JDP2S04E
		Dual	S-MINI	1SV172
			SMQ	1SV237
			USM	1SV252
			USQ	1SV312 JDP4P02U
	Schottky diode	Single	USC	1SS315
			fSC	JDH2S01FS
		Dual	S-MINI	1SS295
			SSM	JDH3D01S*
			VESM	JDH3D01FV*

*: New product

Application	Type	Package	Part Number
RF Amp	Dual-gate MOSFET	SMQ	3SK195
			3SK225 3SK226
		USQ	3SK257 3SK258
	Single-gate MOSFET	MINI	2SK241
		S-MINI	2SK302
		USM	2SK882
		SMQ	2SK1771
	Bipolar transistor	MINI	2SC2668
		S-MINI	2SC2714
		USM	2SC4215
	JFET	MINI	2SK161 2SK192A
		S-MINI	2SK211 2SK210
		USM	2SK881

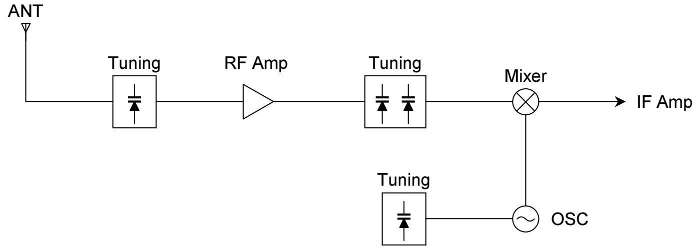
Application	Type		Package	Part Number
Tuning	Tuning varicap diode	Dual	MINI	1SV101
			S-MINI	1SV225 1SV228 JDV3C11 JDV3C34*
	AFC varicap diode	Single	S-MINI	1SV160

*: New product

Application	Type	Package	Part Number
Mixer	Dual-gate MOSFET	SMQ	3SK195
		USQ	3SK260
	Bipolar transistor	MINI	2SC2668
		S-MINI	2SC2714
		USM	2SC4215
		SSM	2SC4915

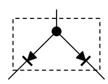
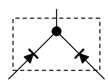
Application	Type	Package	Part Number
OSC	JFET	MINI	2SK192A
		S-MINI	2SK210
	Bipolar transistor	MINI	2SC2668 2SC2995
		S-MINI	2SC2714 2SC2996
		USM	2SC4215
		SSM	2SC4915

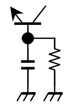
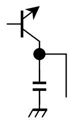
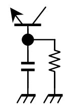
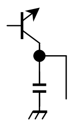
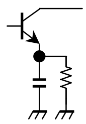
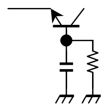
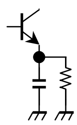
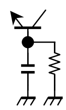
3. Radio-Frequency Devices for TV and VTR Tuners



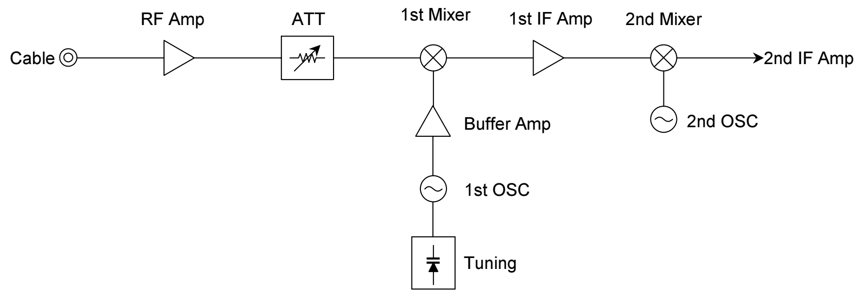
Application	Type	Band	Package	Part Number
Tuning	Tuning varicap diode	Wideband VHF	USC	1SV215 1SV262 1SV288 1SV231 1SV232 1SV269 1SV302
			ESC	1SV282 1SV290B 1SV283B 1SV303
			S-MINI (dual type)	1SV242
		UHF	USC	1SV214
			ESC	1SV278B
	AFC diode	VHF to UHF	USC	1SV216
RF Amp	Dual-gate FET	Wideband VHF	SMQ	3SK195 3SK225 3SK226 3SK292
			USQ	3SK259 3SK257 3SK258 3SK294
		UHF	SMQ	3SK199 3SK207 3SK232 3SK291
			USQ	3SK256 3SK249 3SK293
Mixer	Dual-gate FET	VHF and wideband VHF	USQ	3SK260 3SK259
	Schottky diode	UHF	S-MINI	1SS295 (dual)
			USC	1SS315
			SSM	JDH3D01S* (dual)
			fSC	JDH2S01FS
			VESM	JDH3D01FV* (dual)

*: New product

Application	Type		Band	Internal Connection	Package	Part Number
Tuning	Band switch	Single	VHF and wideband VHF	—	USC	1SS314
					ESC	1SS381
					sESC	JDS2S03S
		Dual		 Common anode	S-MINI	1SS269
						1SS268
					USM	1SS313
				 Common cathode	USM	1SS312
					SSM	1SS364

Application	Type	Band	Circuit Diagram	Package	Part Number
RF Amp	Bipolar transistor	UHF	 Common base	USM	2SC4244
				SMQ	2SC4214
OSC	Bipolar transistor	Wideband VHF	 Common collector	USM	2SC4251 2SC4246 2SC4252
				S-MINI	2SC3124 2SC3121
		UHF	 Common base	USM	2SC4246
				S-MINI	2SC3121
			 Common collector	USM	2SC4247
				S-MINI	2SC3547A
Mixer	Bipolar transistor	Wideband VHF	 Common emitter	USM	2SC4250 2SC4245
				S-MINI	2SC3123 2SC3120
			 Common base	USM	2SC4253 2SC4251 2SC4246
				S-MINI	2SC3125 2SC3124 2SC3121
		UHF	 Common emitter	S-MINI	2SC3120 2SC3862
				S-MINI	2SC3547A
			 Common base	USM	2SC4245
				USM	2SC4247

4. Radio-Frequency Devices for CATV Converters



Application	Type	Package	Part Number
RF Amp	Bipolar transistor	SMQ	2SC5087 *2SC5087R MT4S03A MT4S04A
		USQ	MT4S03AU MT4S04AU MT4S100U MT4S101U *MT4S102U *MT4S104U
		TESQ	MT4S100T MT4S101T *MT4S102T *MT4S104T

Application	Type		Package	Part Number
ATT	Pin diode	Single	S-MINI	1SV128
			USC	1SV271 1SV307
			ESC	1SV308 JDP2S01E JDP2S04E
		Dual	S-MINI	1SV172
			SMQ	1SV237
			USM	1SV252
			USQ	1SV312 JDP4P02U
			TESQ	JDP4P02AT

Application	Type		Package	Part Number
1st Mixer	Schottky diode	Single	S-MINI	1SS154
			fSC	JDH2S01FS
		Dual	S-MINI	1SS271
			SSM	*JDH3D01S
			VESM	*JDH3D01FV

Application	Type	Package	Part Number
1st IF Amp	Bipolar transistor	S-MINI	MT3S03A MT3S04A
		SMQ	MT4S03A MT4S04A MT4S06 MT4S07
		USQ	MT4S03AU MT4S04AU MT4S06U MT4S07U
	Si dual-gate MOSFET	SMQ	3SK199 3SK232 3SK291 3SK292
		USQ	3SK249 3SK293 3SK294

Application	Type	Package	Part Number
2nd Mixer	Schottky diode	S-MINI	1SS154 (single) 1SS271 (dual)
	Si dual-gate MOSFET	SMQ	3SK199 3SK232 3SK291
		USQ	3SK249 3SK293
	Cell pack	SM8	TA4107F

Application	Type	Package	Part Number
Buffer Amp	Bipolar transistor	S-MINI	MT3S03A MT3S04A
		SMQ	MT4S03A MT4S04A MT4S06 MT4S07
		USQ	MT4S03AU MT4S04AU MT4S06U MT4S07U

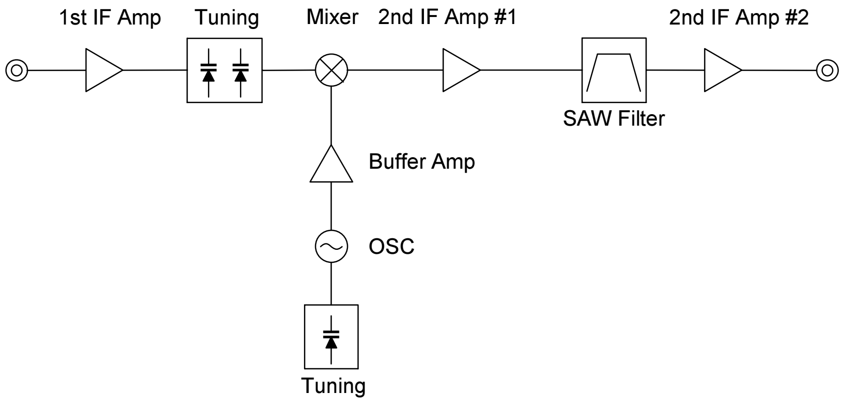
Application	Type	Package	Part Number
1st OSC	Bipolar transistor	S-MINI	2SC5084 MT3S03A MT3S04A
		USM	MT3S03AU MT3S03AU

Application	Type	Package	Part Number
Tuning	Tuning varicap diode	USC	1SV214 1SV230
		ESC	1SV278B

Application	Type	Package	Part Number
2nd OSC	Bipolar transistor	USM	2SC4246
		S-MINI	2SC3121

*: New product

5. Radio-Frequency Devices for SHF 2nd Converters



Application	Type	Package	Part Number
1st IF Amp	Bipolar transistor	SMQ	MT4S03A MT4S04A MT4S06 MT4S07 2SC5092
		USQ	2SC5088 2SC5093 2SC5319 MT4S06U MT4S07U MT4S100U MT4S101U *MT4S102U *MT4S104U
		TESQ	MT4S100T MT4S101T *MT4S102T *MT4S104T

Application	Type	Package	Part Number
Tuning	Preselector and tuning varicap diode	USC	1SV245 1SV287 JDV2S71E
		ESC	1SV309 1SV291 JDV2S71E

Application	Type	Package	Part Number
Mixer	Bipolar transistor	SMQ	2SC5092
	Schottky diode	S-MINI	1SS154 (single) 1SS271 (dual)
		SSM	*JDH3D01S (dual)
		fSC	JDH2S01FS
		VESM	*JDH3D01FV (dual)
	Cell pack	SM8	TA4107F

Application	Type	Package	Part Number
2nd IF Amp #1	Cell pack	SMQ	TA4002F

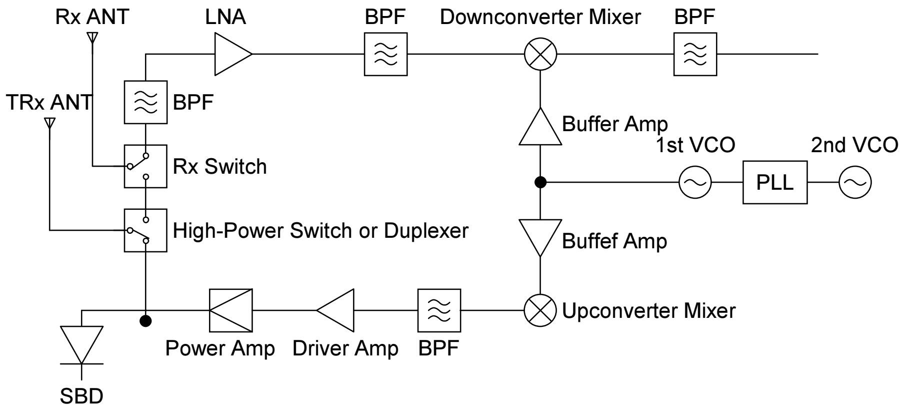
Application	Type	Package	Part Number
2nd IF Amp #2	Cell pack	SM6	TA4000F
		TU6	TA4017FT
		SM8	TA4018F
			TA4019F

Application	Type	Package	Part Number
Buffer Amp	Bipolar transistor	USQ	2SC5088 2SC5093 2SC5319

Application	Type	Package	Part Number
OSC	Bipolar transistor	S-MINI	2SC5089
		USQ	*MT4S200U

*: New product

6. Radio-Frequency Devices for 800-MHz Analog and Digital Cell Phones



Application	Type	Package	Part Number
Power Amp	Si MOSFET	PW-MINI	2SK2854
			2SK2855

Application	Type	Package	Part Number
Rx Switch	GaAs MMIC	TU6	TG2210FT *TG2211AFT
		sES6	TG2213S TG2214S
		CST6B	*TG2217CTB
	PIN diode	fSC	JDP2S02AFS JDP2S05FS
		CST2	JDP2S02ACT JDP2S05CT
		SC2	JDP2S08SC
	Band switch	sESC	JDS2S03S

*: New product

Application	Type	Package	Part Number
Buff Amp	Si cell pack	ESV	TA4011AFE
			TA4012AFE

Application	Package / Type	USC	fSC	SSM	VESM
Detector	SBD	1SS315	JDH2S01FS	JDH3D01S	*JDH3D01FV

*: New product/Dual

Varicap Diode

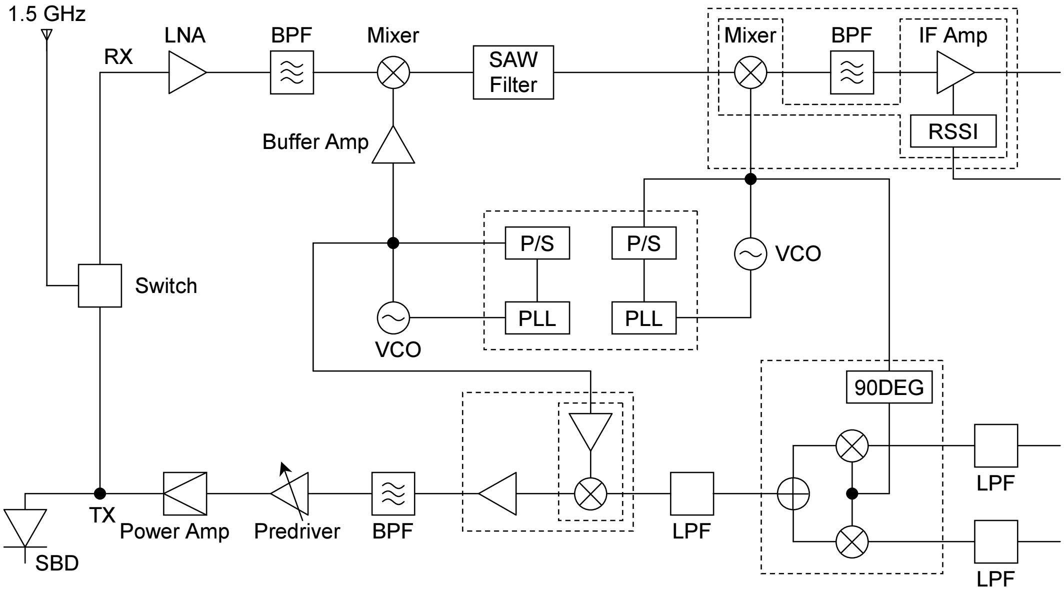
Application \ Package	Type	USC	ESC	sESC	fSC	CST3	SC2
VCO	VCD	1SV229 1SV270 1SV276 1SV304 1SV310	1SV279 1SV281 1SV284 1SV305 1SV311	JDV2S06S JDV2S08S JDV2S09S	JDV2S06FS JDV2S08FS JDV2S09FS *JDV2S26FS *JDV2S27FS *JDV2S28FS	*JDV3S26CT *JDV3S27CT *JDV3S28CT	*JDV2S26SC *JDV2S27SC *JDV2S28SC *JDV2S31SC

*: New product

Application \ Package	Type	TESM	fSM	SMQ	USQ	fS6	CST3	CST6
LNA, Buff Amp	Bipolar transistor	2SC5066FT 2SC5086FT 2SC5091FT 2SC5096FT MT3S03AT MT3S06T MT3S07T MT3S14T MT3S18T MT3S35T MT3S36T MT3S37T MT3S41T	MT3S03AFS MT3S06FS MT3S07FS *MT3S14FS *MT3S18FS MT3S35FS MT3S36FS MT3S37FS MT3S41FS	2SC5087 2SC5092 2SC5097 MT4S06 MT4S07	2SC5088 2SC5093 2SC5098 MT4S06U MT4S07U MT4S32U			
Mixer	Bipolar transistor	2SC5066FT 2SC5086FT 2SC5108FT 2SC5111FT		2SC5087	2SC5088			
VCO	Bipolar transistor	2SC5086FT 2SC5464FT 2SC5066FT 2SC5108FT 2SC5111FT MT3S03AT MT3S04AT MT3S05T MT3S06T MT3S07T MT3S08T MT3S11T MT3S12T MT3S14T MT3S18T MT3S35T MT3S36T MT3S37T MT3S41T MT3S45T	MT3S03AFS MT3S04AFS MT3S05FS MT3S06FS MT3S07FS MT3S08FS MT3S11FS MT3S14FS MT3S18FS MT3S35FS MT3S36FS MT3S37FS MT3S41FS MT3S45FS *MT3S106FS *MT3S107FS			MT6L63FS MT6L64FS MT6L65FS *MT6L66FS *MT6L67FS MT6L68FS MT6L71FS MT6L72FS *MT6L73FS *MT6L74FS *MT6L75FS *MT6L76FS *MT6L77FS MT6L78FS	*MT3S11CT *MT3S106CT	*MT6L66CT *MT6L67CT *MT6L73CT *MT6L74CT *MT6L75CT *MT6L76CT *MT6L77CT

*: New product

7. Radio-Frequency Devices for PDC Phone (1.5 GHz)



Application \ Package / Type		ESC	sESC	fSC	CST3	SC2
VCO	VCD	JDV2S05E 1SV285 1SV305 1SV311 1SV314 1SV329	JDV2S05S JDV2S07S JDV2S08S JDV2S09S JDV2S10S JDV2S13S	JDV2S05FS JDV2S07FS JDV2S08FS JDV2S09FS JDV2S10FS JDV2S13FS *JDV2S25FS *JDV2S26FS *JDV2S27FS *JDV2S28FS	*JDV2S25CT *JDV2S26CT *JDV2S27CT *JDV2S28CT	*JDV2S25SC *JDV2S26SC *JDV2S27SC *JDV2S28SC *JDV2S31SC

*: New product

Application \ Package / Type		ESV
Buff Amp	Si cell pack	TA4011AFE TA4012AFE

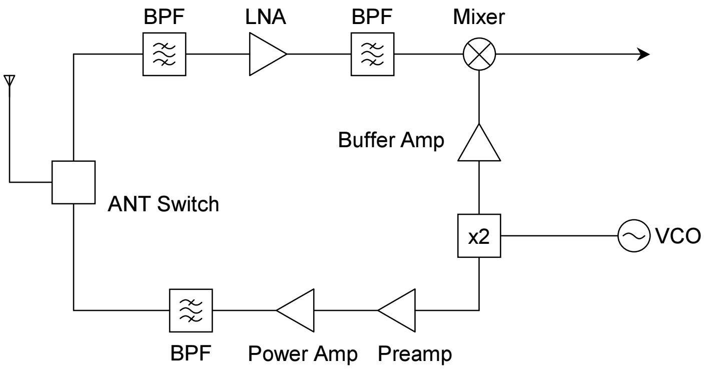
Application \ Package / Type		USC	fSC	SSM	VESM
Detector	SBD	1SS315	JDH2S01FS	JDH3D01S	*JDH3D01FV

*: New product/Dual

Package Application	Type	TESM	fSM	USQ	TESQ	fS6	CST3	CST6
LNA, Buff Amp	Bipolar transistor	2SC5317FT MT3S03AT MT3S06T MT3S07T *MT3S14T *MT3S18T MT3S35T MT3S36T MT3S37T MT3S41T	MT3S06FS MT3S07FS *MT3S14FS *MT3S18FS MT3S35FS MT3S36FS MT3S37FS MT3S41FS	2SC5319 MT4S06U MT4S07U MT4S100U MT4S101U	MT4S100T MT4S101T			
Mixer (downconv.)	Bipolar transistor	2SC5317FT 2SC5086FT						
VCO	Bipolar transistor	MT3S03AT MT3S04AT MT3S05T MT3S06T MT3S07T MT3S08T MT3S11T MT3S12T MT3S14T MT3S18T MT3S35T MT3S36T MT3S37T MT3S41T MT3S45T	MT3S03AFS MT3S04AFS MT3S05FS MT3S06FS MT3S07FS MT3S08FS MT3S11FS MT3S12FS MT3S14FS MT3S18FS MT3S35FS MT3S36FS MT3S37FS MT3S41FS MT3S45FS *MT3S106FS *MT3S107FS			MT6L63FS MT6L64FS MT6L65FS *MT6L66FS *MT6L67FS MT6L68FS MT6L71FS MT6L72FS *MT6L73FS *MT6L74FS *MT6L75FS *MT6L76FS *MT6L77FS MT6L78FS	*MT3S11CT *MT3S106CT	*MT6L66CT *MT6L67CT *MT6L73CT *MT6L74CT *MT6L75CT *MT6L76CT *MT6L77CT

*: New product

8. Radio-Frequency Devices for 900-MHz, 2.4-GHz and 5.8-GHz Band Cordless Phones



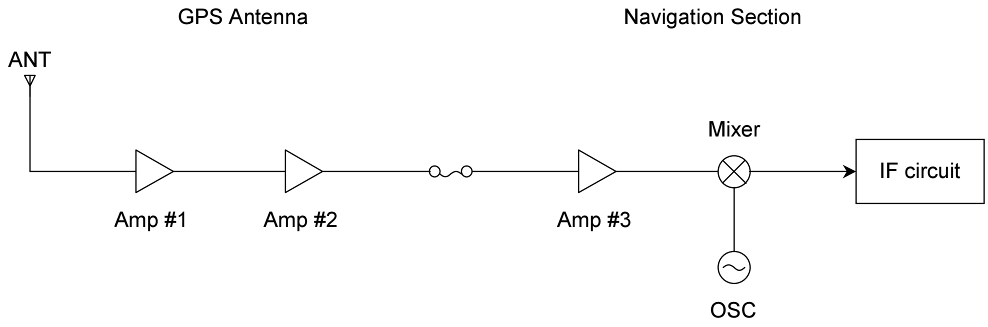
Application	Package / Type	USC	ESC	sESC	fSC	CST2	SC2
ANT Switch	900 MHz	1SV271 1SV307 1SS314	JDP2S04E 1SV308 1SS381	JDP2S02AS JDS2S03S	JDP2S02AFS	JDP2S02ACT	JDP2S08SC
	2.4 GHz	1SV271 1SV307	JDP2S04E 1SV308	JDP2S02AS	JDP2S02AFS JDP2S05FS	JDP2S02ACT JDP2S05CT	
	5.8 GHz				JDP2S05FS	JDP2S05CT	
VCO & Diode	900 MHz	1SV214 1SV229 1SV276 1SV304 1SV310 1SV313	1SV278B 1SV279 1SV284 1SV305 1SV311 1SV314	JDV2S06S JDV2S08S JDV2S09S JDV2S10S	JDV2S06FS JDV2S08FS JDV2S09FS JDV2S10FS		
	2.4 GHz		JDV2S01E JDV2S02E JDV2S05E	JDV2S01S JDV2S02S JDV2S05S JDV2S16S JDV2S19S	JDV2S01FS JDV2S02FS JDV2S05FS JDV2S16FS JDV2S19FS		
	5.8 GHz		JDV2S02E	JDV2S02S *JDV2S17S *JDV2S22S	JDV2S02FS *JDV2S22FS		

*: New product

Application	Package / Type	USM	SSM	TESM	SMQ	USQ	TESQ
VCO Buffer Amp Mixer Power Amp Preamp LNA	900 MHz	2SC5065 2SC5085 MT3S06U *MT3S16U	2SC5066 2SC5086 MT3S06S	2SC5066FT 2SC5086FT MT3S06T *MT3S16T *MT3S18T	2SC5087 MT4S06	2SC5088 MT4S06U	
	2.4 GHz	MT3S06U	MT3S06S	2SC5317FT MT3S06T *MT3S18T MT3S35T MT3S37T MT3S45T	MT4S06	2SC5319 MT4S06U MT4S101U MT4S32U	MT4S101T
	5.8 GHz			MT3S35T MT3S37T		MT4S100U MT4S101U MT4S102U MT4S104U *MT4S200U	MT4S100T MT4S101T MT4S102T MT4S104T

*: New product

9. Radio-Frequency Devices for Global Positioning System (GPS)



GPS Antenna Section

Application	Package / Type	ES6	USQ	TESQ
Amp #2	Bipolar transistor		2SC5319 MT4S32U MT4S100U MT4S101U MT4S102U MT4S104U *TA4S200U	MT4S100T MT4S101T MT4S102T MT4S104T
	Si cell pack	TA4016AFE		*TA4020FT

*: New product

Navigation Section

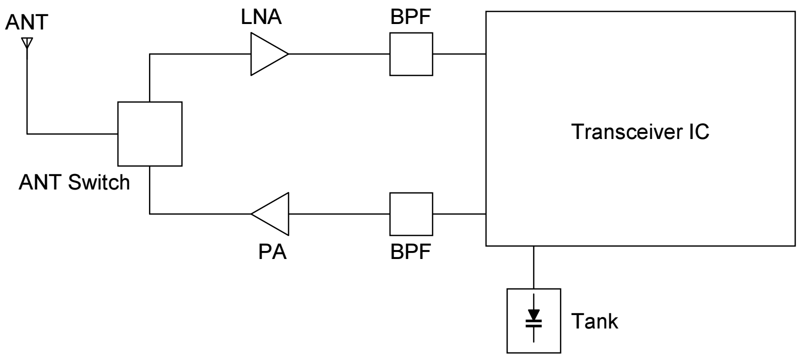
Application	Package / Type	USQ	TESQ
Amp #3	Bipolar transistor	2SC5319 MT4S06U MT4S32U MT4S100U MT4S101U *MT4S102U *MT4S104U	MT4S100T MT4S101T *MT4S102T *MT4S104T
Mixer, OSC	Bipolar transistor	2SC5319 MT4S06U	

*: New product

Application	Package / Type	ESC	sESC	fSC
OSC	Varicap diode	1SV314 1SV329 JDV2S01E JDV2S02E JDV2S05E	JDV2S10S JDV2S13S JDV2S01S JDV2S02S JDV2S05S JDV2S16S *JDV2S17S JDV2S19S *JDV2S22S	JDV2S10FS JDV2S13FS JDV2S01FS JDV2S02FS JDV2S05FS JDV2S16FS JDV2S19FS *JDV2S22FS

*: New product

10. 2.4-GHz Wireless LAN and Bluetooth™



ANT Switch

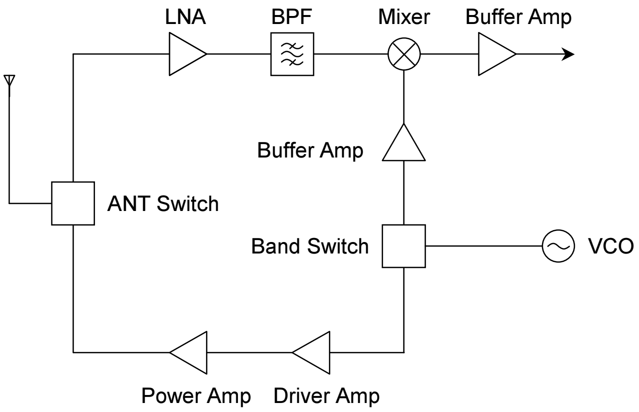
Application	Type	Package	Part Number
ANT Switch for 2.4G WLAN and Class-1 BT	GaAs MMIC	UF6	TG2216TU
ANT Switch for Class-2/3 BT		TU6	TG2210FT *TG2211AFT
		sES6	TG2213S TG2214S
		CST6B	*TG2217CTB

*: New product

Application	Package / Type	USQ	TESQ
LNA	Bipolar transistor	MT4S100U MT4S101U MT4S102U MT4S104U	MT4S100T MT4S101T MT4S102T MT4S104T

Application	Package / Type	ESC	sESC	fSC
VCO	Varicap diode	1SV314 1SV329 JDV2S01E JDV2S02E JDV2S05E	JDV2S10S JDV2S13S JDV2S01S JDV2S02S JDV2S05S JDV2S16S JDV2S19S	JDV2S10FS JDV2S13FS JDV2S01FS JDV2S02FS JDV2S05FS JDV2S16FS JDV2S19FS

11. Radio-Frequency Devices for FRS and GMRS



Application \ Package	Type	USC	ESC	sESC	fSC	CST2	CT2
ANT Switch	FRS, GMRS	1SS314 1SV271 1SV307	1SS381 JDP2S04E 1SV308	JDS2S03S JDP2S02AS	JDP2S02AFS JDP2S05FS	JDP2S02ACT JDP2S05CT	JDP2S08SC
VCO	FRS, GMRS	1SV214 1SV229 1SV276 1SV304	1SV278B 1SV279 1SV284 1SV305 1SV282	JDV2S06S JDV2S08S	JDV2S06FS JDV2S08FS		

Application \ Package	Type	USM	SSM	TESM	SMQ	USQ
VCO Driver Amp Buffer Amp Mixer LNA	FRS, GMRS	2SC5065 2SC5085 MT3S06U *MT3S16U	2SC5066 2SC5086 MT3S06S	2SC5066FT 2SC5086FT MT3S06T *MT3S16T *MT3S18T	2SC5087 MT4S06	2SC5088 MT4S06U

*: New product

Application \ Package	Type	PW-MINI	PW-X
Power Amp	FRS	2SK3078A *2SK3656	
	GMRS		2SK3079A *2SK3756

*: New product

[5] Maximum Ratings and Electrical Characteristics

[5] Maximum Ratings and Electrical Characteristics

1. Definition of Maximum Ratings

1.1 Maximum Ratings (for radio-frequency bipolar transistors)

1) Collector–base voltage (V_{CBO})
Maximum permissible value of voltage between collector and base with emitter open at the specified ambient temperature

2) Collector–emitter voltage (V_{CEO})
Maximum permissible value of voltage between collector and emitter with base open at the specified ambient temperature

3) Emitter–base voltage (V_{EBO})
Maximum permissible value of voltage between emitter and base with collector open at the specified ambient temperature

4) Collector current (I_C)
Maximum permissible value of collector current at the specified ambient temperature.
Regardless of the states of base and emitter, a current exceeding the rated value cannot flow through the collector.

5) Base current (I_B)
Maximum permissible value of base current at the specified ambient temperature.
Regardless of the states of collector and emitter, a current exceeding the rated value cannot flow through the base.

6) Collector power dissipation (P_C)
Collector power dissipation (P_C) is the maximum rating for power consumed at the collector junction at room temperature. P_C decreases with increase in ambient temperature. If a device dissipates power in excess of the P_C rating, it may be damaged electrically or thermally due to the generation of heat. Note also that the specified P_C value is the value for the device alone. If the device is mounted on a PCB, its P_C value will differ substantially.

7) Junction temperature (T_j)
Permissible junction temperature range for device operation. The maximum power consumption and operating temperature levels of the device must be set so that the junction temperature always remains within the T_j range.

8) Storage temperature (T_{stg})
Ambient temperature range within which the device must be stored while not being used. Toshiba guarantees that the device will not be degraded if it is stored at a temperature within the T_{stg} range.

1.2 Maximum Ratings (for junction FETs, GaAs MESFETs and MODFETs)

1) Gate–drain voltage (V_{GDO}, V_{GDS})

Maximum permissible value of reverse voltage between gate and drain with source open (V_{GDO}) or with source and drain shorted (V_{GDS}) at the specified ambient temperature.

2) Gate–source voltage (V_{GS})

Maximum permissible value of reverse voltage between gate and source under the specified condition of drain at the specified ambient temperature.

3) Gate current (I_G)

Maximum permissible value of forward current for conductive gate at the specified ambient temperature.

Regardless of the states of source and drain, a current exceeding the rated value cannot flow through the gate.

4) Power dissipation (P_D)

Maximum permissible power dissipation at the specified ambient temperature. Normally, the value is specified for room temperature. P_D decreases with increase in ambient temperature. If a device dissipates power in excess of the P_D rating, it may be damaged electrically or thermally due to the generation of heat. Note also that the specified P_D value is the value for the device alone. If the device is mounted on a PCB, its P_D value will differ substantially.

5) Channel temperature (T_{ch})

Permissible channel temperature range for device operation. The maximum power consumption and operating temperature levels of the device must be set so that the channel temperature always remains within the T_{ch} range.

6) Junction temperature (T_j)

Permissible junction temperature range for device operation. The maximum power consumption and operating temperature levels of the device must be set so that the junction temperature always remains within the T_j range.

7) Storage temperature (T_{stg})

Ambient temperature range within which the device must be stored while not being used. Toshiba guarantees that the device will not be degraded if it is stored at a temperature within the T_{stg} range.

1.3 Maximum Ratings (for MOSFETs)

1) Drain–source voltage (V_{DS})

Maximum permissible value of voltage between drain and source under the specified gate condition at the specified ambient temperature. When the gate is open, a floating voltage may be generated, causing excessive current (I_D) flow and damage to the device.

2) Gate–source voltage (V_{GS})

Maximum permissible value of voltage between gate and source under the specified condition of drain at the specified ambient temperature. The plus/minus (±) symbol before the value indicates that the voltage can be applied in both positive and negative directions.

3) Drain current (I_D)

Maximum permissible value of current flowing to drain at the specified ambient temperature.

4) Power dissipation (P_D)

Maximum permissible power dissipation at the specified ambient temperature. Normally, the value is specified for room temperature. P_D decreases with increase in ambient temperature. If a device dissipates power in excess of the P_D rating, it may be damaged electrically or thermally due to the generation of heat. Note also that the specified P_D value is the value for the device alone. If the device is mounted on a PCB, its P_D value will differ substantially.

5) Channel temperature (T_{ch})

Permissible channel temperature range for device operation. The maximum power consumption and operating temperature levels of the device must be set so that the channel temperature always remains within the T_{ch} range.

6) Junction temperature (T_j)

Permissible junction temperature range for device operation. The maximum power consumption and operating temperature levels of the device must be set so that the junction temperature always remains within the T_j range.

7) Storage temperature (T_{stg})

Ambient temperature range within which the device must be stored while not being used. Toshiba guarantees that the device will not be degraded if it is stored at a temperature within the T_{stg} range.

1.4 Maximum Ratings (for radio-frequency small-signal amplifier ICs, mixer ICs and oscillation ICs)

1) Power supply voltage (V_{CC})

Absolute maximum voltage that can be applied between the V_{CC} pin and GND of a radio-frequency IC.

2) Power supply current (I_{CC})

Absolute maximum current that can flow in the entire circuit when voltage is applied between the V_{CC}/V_{DD} pin and GND of a radio-frequency IC.

3) Power dissipation (P_D)

Maximum permissible power dissipation for one IC. Normally, the value is specified for room temperature. P_D decreases with increase in ambient temperature. If a device dissipates power in excess of the P_D rating, it may be damaged electrically or thermally due to the generation of heat. Note also that the specified P_D value is the value for the device alone. If the device is mounted on a PCB, its P_D value will differ substantially.

4) Operating temperature (T_{opr})

Permissible ambient temperature range for IC operation. Toshiba guarantees that the device will operate properly if it is used within this range. However, for devices whose electrical characteristics are specified for T_a = 25°C, operation cannot be fully guaranteed over the entire range.

5) Junction temperature (T_j)

Permissible junction temperature range for device operation. The maximum power consumption and operating temperature levels of the device must be set so that the junction temperature always remains within the T_j range.

6) Storage temperature (T_{stg})

Ambient temperature range within which the device must be stored while not being used. Toshiba guarantees that the device will not be degraded if it is stored at a temperature within the T_{stg} range.

1.5 Maximum Ratings (for power amp ICs)

1) Power supply voltage (V_{DD})

Absolute maximum voltage that can be applied between the V_{DD} pin and GND of a power amp IC.

2) Gate voltage (V_{GG})

Absolute maximum voltage that can be applied between the V_{GG} pin and GND of a power amp IC.

3) Input power (P_i)

Maximum permissible value of power that can be input on the Pi pin of a power amp IC.

4) Power dissipation (P_D)

Maximum permissible power dissipation for one IC. Normally, the value is specified for room temperature. P_D decreases with increase in ambient temperature. If a device dissipates power in excess of the P_D rating, it may be damaged electrically or thermally due to the generation of heat. Note also that the specified P_D value is the value for the device alone. If the device is mounted on a PCB, its P_D value will differ substantially.

5) Operating temperature (T_{opr})

Permissible ambient temperature range for IC operation. Toshiba guarantees that the device will operate properly if it is used within this range. However, for devices whose electrical characteristics are specified for T_a = 25°C, operation cannot be fully guaranteed over the entire range.

6) Storage temperature (T_{stg})

Ambient temperature range within which the device must be stored while not being used. Toshiba guarantees that the device will not be degraded if it is stored at a temperature within the T_{stg} range.

1.6 Maximum Ratings (for switching ICs)

1) Power voltage (V_{DD})

Absolute maximum voltage that can be applied between the V_{DD} pin and GND of a switching IC.

2) Control voltage (V_C) or (V_{CON})

Absolute maximum voltage that can be applied between the V_C or V_{CON} pin and GND of a switching IC.

3) Input power (P_i)

Maximum permissible value of power that can be input on the Pi pin of a switching IC.

4) Power dissipation (P_D)

Maximum permissible power dissipation for one IC. Normally, the value is specified for room temperature. P_D decreases with increase in ambient temperature. If a device dissipates power in excess of the P_D rating, it may be damaged electrically or thermally due to the generation of heat. Note also that the specified P_D value is the value for the device alone. If the device is mounted on a PCB, its P_D value will differ substantially.

5) Operating temperature (T_{opr})

Permissible ambient temperature range for IC operation. Toshiba guarantees that the device will operate properly if it is used within this range. However, for devices whose electrical characteristics are specified for T_a = 25°C, operation cannot be fully guaranteed over the entire range.

6) Storage temperature (T_{stg})

Ambient temperature range within which the device must be stored while not being used. Toshiba guarantees that the device will not be degraded if it is stored at a temperature within the T_{stg} range.

2. Definition of Electrical Characteristics

2.1 Electrical Characteristics (for radio-frequency bipolar transistors)

Parameter	Symbol	Description
Collector cutoff current	I_{CBO}	Collector leakage current which flows when the specified reverse voltage is applied between collector and base with emitter open
Emitter cutoff current	I_{EBO}	Emitter leakage current which flows when the specified reverse voltage is applied between emitter and base with collector open
Collector–emitter breakdown voltage	$V_{(BR)\ CEO}$	Breakdown voltage between collector and emitter when the specified voltage is applied between collector and emitter with emitter grounded and base open
DC current gain	h_{FE}	Ratio of collector current to base current when the device is operating at the specified collector–emitter voltage and collector current and with emitter grounded
Reverse transfer	C_{re}	Capacitance between collector and base at the specified collector–base voltage with emitter grounded
Output capacitance	C_{ob}	Capacitance between collector and base at the specified collector–base voltage with base grounded
Collector–base time constant	$C_c \cdot r_{bb}'$	Product of C_c (capacitance between collector and base) and r_{bb}' (base-spreading resistance) when the device is operating at the specified collector–base voltage and emitter current with base grounded
Collector–base saturation voltage	$V_{CE\ (sat)}$	Voltage between collector and emitter when base–emitter and base–collector currents are forward-biased and the emitter is grounded. Collector current and base current must be specified.
Base–emitter saturation voltage	$V_{BE\ (sat)}$	Voltage between base and emitter when base–emitter and base–collector currents are forward-biased and emitter is grounded. Collector current and base current must be specified.
Transition frequency	f_T	Frequency when $\|hfe\| < 1$ and the device is operating at the specified collector–emitter voltage and the collector current with emitter is grounded
Insertion gain	$\|S_{21e}\|^2$	Forward transfer coefficient at the specified temperature, with specified bias, specified signal source and impedance loading
Power gain	G_{pe}	Small-signal power gain when the input and output circuits are gain-matched at the specified temperature and with the specified bias
Noise figure	NF	Noise figure when the input circuit is noise-matched and output circuit is gain-matched at the specified temperature and with the specified bias

2.2 Electrical Characteristics (for junction FETs, GaAs MESFETs and MODFETs)

Parameter	Symbol	Description
Gate leakage current	I_{GSS}	Gate current when the specified gate voltage is applied with source common, and drain and source short-circuited
Gate–drain breakdown voltage	$V_{(BR)\ GDO}$	Breakdown voltage between gate and drain when the specified gate current flows with drain common and source open
Drain current	I_{DSS}	Drain current when the specified drain voltage is applied with gate and source short-circuited and source common
Gate–source cutoff voltage	$V_{GS\ (OFF)}$	Gate voltage at which the specified drain current flows when the specified drain voltage is applied with source common
Forward transfer admittance	$\lvert Y_{fS} \rvert$	Admittance obtained at $\Delta I_D/\Delta V_{GS}$ when the device is operating at the specified frequency with source common and with the specified drain current and drain voltages applied
Input capacitance	C_{iss}	Equivalent capacitance between gate and source when the device is operating at the specified frequency with source common, drain and source common and with the specified drain current and drain voltages applied
Reverse transfer capacitance	C_{rss}	Equivalent capacitance between gate and drain when the device is operating at the specified frequency with source common and with the specified drain current and drain voltages applied
Power gain	G_{ps}	Small-signal power gain when the input and output circuits are gain-matched
Associated power gain at minimum NF	Ga	Power gain when the input circuit is noise-matched and output circuit is gain-matched
Noise figure	NF	Noise figure when the input circuit is noise-matched and output circuit is gain-matched

2.3 Electrical Characteristics (for MOSFETs)

Parameter	Symbol	Description
Gate leakage current	I_{GSS}	Gate current when the specified gate voltage is applied with source common, and drain and source shorted
Source–drain voltage	V_{DSX}	Source–drain voltage when the specified drain current flows with source common, and specified gate-off bias voltage applied
Source–drain breakdown voltage	$V_{(BR)\ DSX}$	Breakdown voltage between source and drain when the specified drain current flows with source common, and specified gate-off bias voltage applied
Drain current	I_{DSS}	Drain current when the specified drain voltage is applied with gate and source short-circuited and source common
Gate–source cutoff voltage	$V_{GS\ (OFF)}$	Gate voltage at which the specified drain current flows when the specified drain voltage is applied with source common
Forward transfer admittance	$\lvert Y_{fS} \rvert$	Admittance obtained at $\Delta I_D/\Delta V_{GS}$ when the device is operating at the specified frequency with source common and with the specified drain current and drain voltages applied
Input capacitance	C_{iss}	Equivalent capacitance between gate and source when the device is operating at the specified frequency with source common, drain and source short-circuited, and with the specified gate voltage and drain voltage applied
Reverse transfer capacitance	C_{rss}	Equivalent capacitance between gate and drain when the device is operating at the specified frequency with source common, drain and source common, and with the specified gate voltage and drain voltage applied
Power gain	G_{ps}	Small-signal power gain when the input and output circuits are gain-matched
Noise figure	NF	Noise figure when the input circuit is noise-matched and the output circuit is gain-matched

2.4 Electrical Characteristics (for radio-frequency amplifier ICs)

Parameter	Symbol	Description
Power supply current	I_{CC}	Current flowing in the entire circuit when the specified voltage is applied to the V_{CC} pin at the specified temperature
Power gain	$\lvert S_{21}\rvert^2$	Forward transfer coefficient at the specified temperature, with specified bias, specified signal source and impedance loading
Isolation	$\lvert S_{12}\rvert^2$	Reverse transfer coefficient at the specified temperature, with specified bias, specified signal source and impedance loading
Input return loss	$\lvert S_{11}\rvert^2$	Input reflection coefficient at the specified temperature, with specified bias, specified signal source and impedance loading
Output return loss	$\lvert S_{22}\rvert^2$	Output counter coefficient at the specified temperature, with specified bias, specified signal source and impedance loading
Noise figure	NF	Noise figure at the specified temperature, with specified bias, specified signal source and impedance loading
Bandwidth	BW	Frequencies at which power gain $\lvert S21\rvert^2$ is attenuated by 3dB relative to the specified frequency
Output power	P_o1dB	Power output for which power gain $\lvert S21\rvert^2$ is 1dB less than power gain for a small-signal input
Maximum power	P_O	Maximum output power of device at the specified temperature, with specified bias, specified signal source and impedance loading

2.5 Electrical Characteristics (for mixer ICs)

Parameter	Symbol	Description
Power supply current	I_{CC}	Current flowing in the entire circuit when the specified voltage is applied to the V_{CC} pin at the specified temperature
Conversion gain	G_{MIX}, G_C, C_{Gain}	Power ratio of frequency-converted output signal level to input signal level at the specified temperature, with specified bias, specified signal source and impedance loading
Conversion noise figure	NF	Conversion noise figure at the specified temperature, with specified bias, specified signal source and impedance loading. This parameter is expressed as a DSB measurement unless otherwise specified
3rd intermodulation distortion	IM3	Power ratio of frequency-converted desired power to 3rd intermodulation distorted power at the specified temperature, with specified bias, specified signal source and impedance loading
3rd intermodulation distortion intercept pointer	IIP3	Calculated using conversion gain and IM3 as follows: IIP3 = Pin + IM3/2
Maximum power	P_O	Maximum output power of device at the specified temperature, with specified bias, specified signal source and impedance loading

2.6 Electrical Characteristics (for oscillator ICs)

Parameter	Symbol	Description
Power supply current	I_{CC}	Current flowing in the entire circuit when the specified voltage is applied to the V_{CC} pin at the specified temperature
OSC B pin voltage	V_{OSCB}	VOSC B pin voltage when the specified voltage is applied to the V_{CC} pin at the specified temperature
OSC E pin voltage	V_{OSCE}	VOSC E pin voltage when the specified voltage is applied to the V_{CC} pin at the specified temperature
Buff B pin voltage	V_{BuffB}	VBuff B pin voltage when the specified voltage is applied to the V_{CC} pin at the specified temperature
Fout pin voltage	V_{FOUT}	Fout pin voltage when the specified voltage is applied to the V_{CC} pin at the specified temperature

2.7 Electrical Characteristics (for power amp ICs)

Parameter	Symbol	Description
Frequency range	f_{RANGE}	Frequency range for which radio-frequency device characteristics are guaranteed
Total current	I_t	Total power supply current when the specified power supply voltage is applied to each V_{dd} pin at the specified output power level
Gate current	I_G	Power supply current when the specified power supply voltage is applied to the V_G pin
Output power	P_O	Power output when the specified power is input
Small-signal gain	G_P	Power gain when the specified power is input
Adjacent-channel leakage power ratio	ACPR (ACLR)	Ratio of specified bandwidth power to power leaked to adjacent channels at the specified input power, power supply voltage and control voltage levels
Harmonics	2f0	Secondary radio frequency when the specified power is input at the specified frequency and the specified power supply voltage and gate voltage are applied
	3f0	Tertiary frequency when the specified power is input at the specified frequency and the designated power supply voltage and gate voltage are applied
Input VSWR	$VSWR_{in}$	Output side standing-wave ratio when the specified power is input and the specified power supply voltage and gate voltage are applied
Output VSWR	$VSWR_{out}$	No abnormality during operation in any phase of the specified VSWR load when the specified power is input at the specified frequency and the specified power supply voltage and gate voltage are applied
Load-resistance characteristics	—	No abnormality during operation in any phase of the specified VSWR load when the specified power is input at the specified frequency and the specified power supply voltage and gate voltage are applied.
Stability	—	Operational stability (i.e., no abnormal oscillation) after operation in all phases of the specified VSWR load when the specified power is input at the specified frequency and the specified power supply voltage and gate voltage are applied

2.8 Electrical Characteristics (for switching ICs)

Parameter	Symbol	Description
Insertion loss	L_{oss}	Level of attenuation when the specified power is input between the pins at switch-on
Isolation	I_{SL}	Level of attenuation when the specified power is input between the pins at switch-off
Switching time	t_{sw}	Time required after switching for the radio-frequency power level to rise from 10% to 90% of level prior to switching
Power supply current	I_{DD}	Power supply current when the specified power supply voltage is applied to the V_{DD} pin
Control current	I_C	Control current when the specified power supply voltage is applied to the V_{con} pin
Output power 1dB compression point	P_o1dB	Power output at the specified control voltage when the actual output power is attenuated by 1dB relative to the ideal output level on an increase in the input power
Input power 1dB compression point	P_i1dB	Power input at the specified control voltage when the actual output power is attenuated by 1dB relative to the ideal output level on an increase in the input power
Adjacent-channel leakage power ratio	ACPR	Ratio of specified bandwidth power to power leaked to adjacent channels at the specified input power, power supply voltage and control voltage levels

[6] Device Features in Detail

[6] Device Features in Detail

1. Radio-Frequency Transistor Parameter

The main design parameters of a transistor include the device parameters, which are closely related to the internal operating mechanism of the transistor, and the circuit parameters, which compose a matrix obtained by regarding the transistor as a terminal circuit network.

The circuit parameters are divided into small-signal equivalent circuits (analog circuits) and large-signal equivalent circuits (digital circuits), the two groups being differentiated by the amplitude of the signals they handle.

Equivalent circuits have undergone very rapid development recently. In selecting an appropriate equivalent circuit, circuit designers pay close attention to the application ranges and operating limits of the device being simulated. Table 1.1 lists equivalent circuits at present employed in small-signal applications.

Although Table 1.1 lists the frequency used equivalent circuits, this section gives only descriptions of generic small-signal equivalent circuits.

Table 1.1 List of Transistor Equivalent Circuits

- Transistor equivalent circuits
  - Small-signal equivalent circuits (general linear circuits for amplification, oscillation, modulation, and demodulation)
    - Device parameters
      - Early T-type equivalent circuits (common base circuits)
      - Giacoletto's π-type equivalent circuits (emitter and collector common circuits)
    - Circuit parameters
      - Matrices showing the relations between inputs and outputs by voltage and current
        - a, b matrices;
        - g, h matrices (low frequency);
        - y, z matrices (radio frequency)
      - Matrices showing the relations between inputs and outputs by power
        - s matrices (radio frequency)
  - Large-signal equivalent circuits (nonlinear circuits such as pulse, digital, and switching circuits)
    - Current control model by Evers-Moll;
    - Current control model by Beaufoy-Sparkes;
    - Current control model by Linville;
    - Other nonlinear models

1.1 Device Parameters

1.1.1 Early T-Type Equivalent Circuits

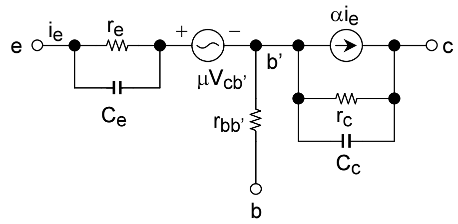


Figure 1.1 Early T-Type Equivalent Circuit

Figure 1.1 shows an Early T-type equivalent circuit.

In this circuit, r_e is emitter resistance.

The forward-biased resistance associated with the base-to-emitter junction is represented by the following equation:

$$r_e = \frac{kT}{qI_E}\,(\Omega) \quad \text{.......................................} (1)$$

where

k: Boltzman's constant (1.38×10^{-23} J/K),

T: absolute temperature (K),

Q: electric charge of electron (1.60×10^{-19} C),

I_E: emitter current (A).

Equation (1) is changed as follows at normal temperature (300 K) if the emitter current is represented by mA in:

$$r_e = \frac{26}{I_E(mA)}\,(\Omega) \quad \text{.......................................} (2)$$

C_e is emitter capacitance (C_{T_e} + C_{D_e}).

The emitter capacitance is represented as a sum of the depletion layer capacitance and the diffusion capacitance. Because the depletion layer capacitance in an emitter-to-base junction is normally far smaller than the diffusion capacitance, it can in most cases be ignored. The depletion layer capacitance C_{T_e} and the diffusion capacitance C_{D_e} are represented as

$$C_{T_e} = A_e\sqrt{\frac{\frac{1}{2}\varepsilon q n_N}{\phi_0 - V_{b'e}}}\,(F) \quad \text{.......................................} (3)$$

where,

A_e: emitter junction area (m^2),

ε: permittivity,

n_N: majority carrier density (m^{-3}) on the side of the higher specific resistance side (NPN in this case),

ϕ_0: contact potential difference (potential fault ck. term when balanced) (V),

$V_{b'e}$: potential applied to both ends of the base-to-emitter junction (1).

$$C_{D_e} = \frac{qI_EW^2}{2kTD}\,(F) \quad \text{.......................................} (4)$$

where,

W: base width (m),

D: diffusion coefficient of minority carrier in the base region (m^2/s), μ is voltage feedback ratio (early constant).

This constant, measuring what is known as the Early effect, is a base-width modulation parameter,

$$\mu = \frac{kTd_c}{3qW(\phi_0 - V_{b'e})} \quad \text{.....(5)}$$

where,

d_c: width of collector depletion lay (m),

r_c is collector resistance.

This is a kind of base-width modulation parameter, represented as follows:

$$r_c = \frac{1}{I_E\left(\frac{\partial\alpha}{\partial V_{b'c}}\right)}(\Omega) \quad \text{.....(6)}$$

The value of rc is usually 1 to 2 MΩ or so.

C_c is collector capacitance.

Calculated similarly to emitter capacitance, this is shown as the sum of depletion layer capacitance and diffusion capacitance of the collector-to-base junction. However, since the diffusion capacitance of the collector-to-base junction is far smaller than the depletion layer capacitance, it can be ignored. The depletion layer capacitance is represented as

$$C_{TC} = A_C\sqrt[3]{\frac{\frac{\varepsilon^2 qa}{12}}{\phi_0 - V_{b'c}}}\ (F) \quad \text{.....(7)}$$

where,

A_C: collector junction area (m^2),

a: impurity concentration gradient (m^{-4}),

$V_{b'e}$: potential applied to both ends of the base-to-collector junction (V).

Usually the value of C_c is one to ten pF.

α is DC forward current transfer ratio.

This is the only parameter that depends on frequency, among the several related to an Early T-type equivalent circuit, and is represented by the following equations:

$$\alpha = \frac{\alpha_0}{1 + j\omega C_e r_e},$$

$$f_\alpha = \frac{1}{2\pi C_e r_e}$$

therefore,

$$\alpha = \frac{\alpha_0}{1 + j\frac{f}{f_\alpha}} \quad \text{.....(8)}$$

where,

α_0: value of α at low frequency

f_α : α-interrupting frequency (frequency at which α is reduced to a level 3 dB less than α_0)

Figure 1.2 shows the frequency locus of α. During actual measurement of α, the difference between theoretical and measured values increases as the frequency approaches f_α. This is because the Early equivalent circuit is based on a first approximation of physical phenomena.

To correct this difference, Thomas-Moll introduced excess phase m and provided the following equation:

$$\alpha = \frac{\alpha_0}{1 + j\frac{f}{f_\alpha}} \exp\left(-jm\frac{f}{f_\alpha}\right) \quad \text{(9)}$$

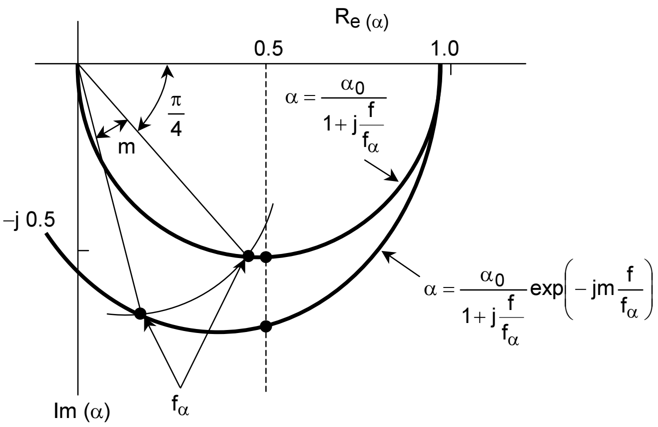


Figure 1.2 Frequency Locus of α

The above equation agrees well with measured values in frequencies less than f_α.

$r_{bb'}$ is base diffusion resistance.

This is resistance from the center of the base area to the external base terminal, which actually contributes to transistor action. It is determined according to the shape and dimensions of the transistor, and the base specific resistance.

$$r_{bb'} \simeq \frac{q_B}{8\pi W}(\Omega) \quad \text{(10)}$$

where,

q_B: specific resistance of base area ($\Omega \cdot$m).

DC current gain (β) at the common emitter is represented as follows:

$$\beta = \frac{\alpha_0}{1-\alpha_0} \frac{1}{1 + j\omega C_{b'e} r_{b'e}} = \frac{\beta_0}{1 + j\omega C_{b'e} r_{b'e}} .$$

The β-interrupting frequency f_β is defined as the frequency at which the absolute value of β becomes $\beta_0/\sqrt{2}$. In a similar manner to f_α, f_β is expressed as

$$f_\beta = \frac{1}{2\pi C_{b'e} r_{b'e}} ,$$

therefore,

$$\beta = \frac{\beta_0}{1 + j\frac{f}{f_\beta}} \quad \text{(11)}$$

1.1.2 Giacoletto's π-Type Equivalent Circuit

Figure 1.3 shows a π-type equivalent circuit. This equivalent circuit is in itself the same as the Early T-type equivalent circuit mentioned above. The only thing distinguishing the π-type circuit from the Early T-type equivalent circuit is that, in principle, each parameter has no frequency response.

Table 1.2 Relationship between Parameters of the π-Type and T-Type Equivalent Circuits

π-Type Equivalent Circuit Parameters	T-Type Equivalent Circuit Parameters
$C_{b'e}$	C_e
$r_{be'}$	$\frac{r_e}{1-\alpha_0}$
$C_{b'c}$	C_c
$\frac{1}{r_{b'c}}$	$\frac{1}{r_c}-\frac{\mu(1-\alpha_0)}{r_e}$
r_{ce}	$\frac{r_e}{\mu}$
g_m	$\frac{\alpha_0}{r_e}$
$r_{bb'}$	$r_{bb'}$

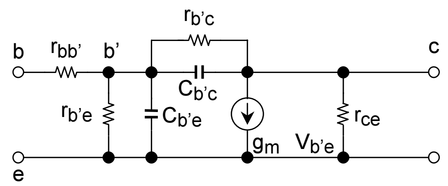


Figure 1.3 π-Type Equivalent Circuit

Parameters of the T-type equivalent circuit and those of the π-type have the correlation shown in Table 1.2.

Because the physical meaning of each parameter is easy to understand, this circuit is very commonly employed. When the circuit is actually being employed for circuit calculation, it will prove convenient if the basic style shown in Figure 1.3 is slightly simplified by restricting the frequency range to that which is anticipated for performance of the device actually being simulated.

1.1.3 Types and Structures of Field Effect Transistors (FETs)

Field Effect Transistors (FETs) can be classified into the following two types according to their gates:

- Junction FET (junction gate)
- MOSFET (insulated gate)

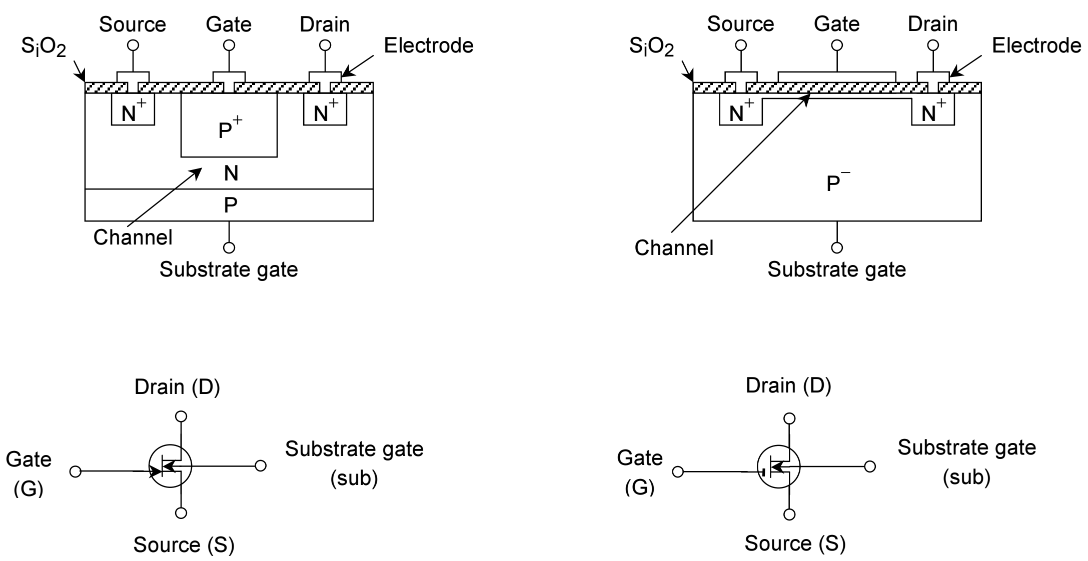
Figure 1.4 shows the structures of both types.

A junction FET is one whose gate-to-channel portion is composed of a PN junction; but a FET whose gate-to-channel portion is composed of Metal, Oxide, and a Semiconductor is termed a MOSFET. FETs are also classified into P-channel and N-channel types, according to the type (P or N) of the semiconductor layer through which drain current flows.

The structural drawings shown in Figure 1.4 are all N-channel type.

Both junction and MOSFETs have their merits and disadvantages. A MOSFET is much more easily damaged by static electricity. Extreme care must be exercised, and suitable protective measures taken, when handling a MOSFET.

(1) Junction FET (2) MOSFET



*: The substrate gate is usually connected to the source.

*: The substrate gate is usually connected to the source.

Figure 1.4 Structures and Symbols of Field Effect Transistors (FETs)

However, almost all MOSFETs incorporate a protective diode at the gate to prevent such breakdowns, and it is very rare for them to degenerate when handled in a careful manner.

Nevertheless, junction FETs are considerably more robust, and are usually not damaged even if handled in the same manner as bipolar transistors.

Almost all MOSFETs are used for radio-frequency circuits and chopper circuits. This is because, compared with the junction type, the MOS type is superior in cross-modulation and inter-modulation characteristics; and, when used in a chopper circuit, the MOS type exhibits less spike and a higher switching speed.

When using FETs for a radio-frequency circuit, it is necessary to reduce the internal feedback capacitance to as low a level as possible, so that stable gain can be obtained. FETs with a cascode connection are employed for this purpose.

In recent years, this reduced internal feedback has been achieved in two different ways: by producing a cascode FET in which two FETs are internally cascode-connected, and by development of dual-gate MOSFETs.

Figure 1.5 illustrates the structure of a cascode FET and provides a drawing of an equivalent connection for it. A cascode FET has two junction gates, the one near the drain being connected to the substrate gate. Thereby two FETs are produced: a common source FET and a common gate FET.

This structure causes feedback from the drain to be grounded as alternate current, producing a FET with small reverse transfer capacitance.

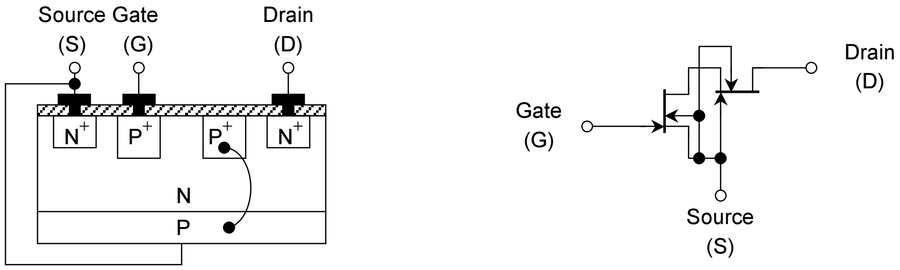


Figure 1.5 Structure and Equivalent Connection Drawing of a Cascode FET

Figure 1.6 shows the structure and equivalent connection drawings of a dual-gate MOSFET. As far as the operating principle is concerned, this FET is identical with a cascode FET. In the dual-gate MOSFET, Gate 2 is led out to be grounded for AC, and supplied with positive bias voltage for DC, when the FET is used in a radio-frequency amplifier circuit. It is possible to use Gate 2 as an injection terminal when using the MOSFET in a mixing circuit.

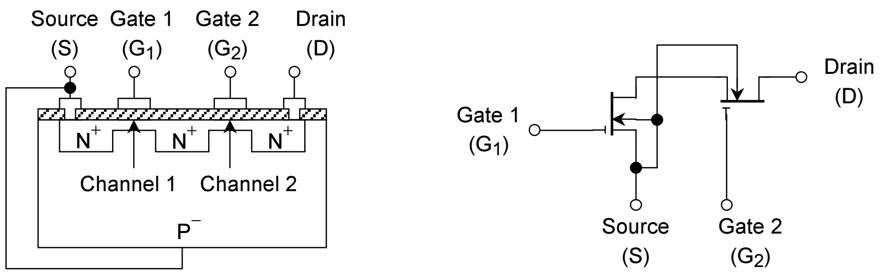


Figure 1.6 Structure and Equivalent Connection Drawings of a Dual-Gate MOSFET

The symbols used for a junction cascode FET and for a dual-gate MOSFET are illustrated in Figure 1.7.

(1) Junction cascode FET

(2) Dual-gate MOSFET

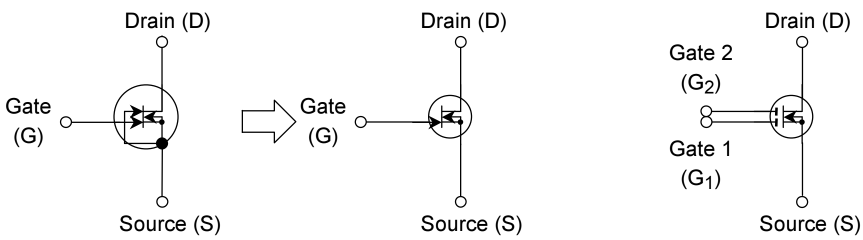


Figure 1.7 Symbols Used for Junction Cascode FET and Dual-Gate MOSFET

Other available FETs, in addition to those already described, include a power FET and a GaAs FET.

1.1.4 FET Equivalent Circuits

As in the case of bipolar transistors, a FET can be simulated by means of an equivalent circuit. Figure 1.8 is a schematic diagram of the structure of this equivalent circuit.

This diagram appears in a more schematic form in the equivalent circuit in Figure 1.9 (a), and is further modified into a practical, simplified equivalent circuit in Figure 1.9 (b).

C_{GD}, C_{GS}, and C_{DS} shown here are parasitic capacitances. Since their values are relatively small, it is possible to ignore them unless this circuit is used in VHF regions.

However, these capacitances must be fully taken into account when transistors with large interelectrode capacitances, such as power FETs and high-g_m FETs, are used in low-frequency regions.

For a FET to be used in chopper circuits, it is necessary to keep the difference between C_{GD} and C_{GS} small to prevent spikes.

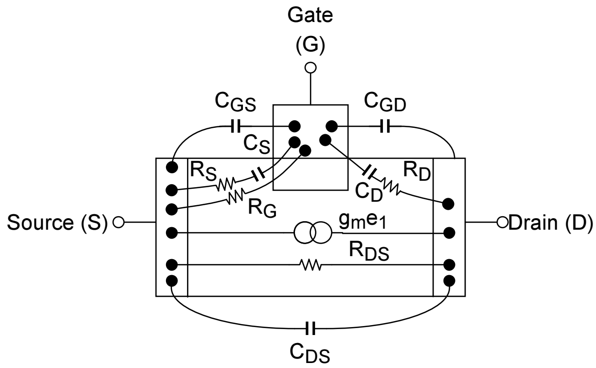


Figure 1.8 Equivalent Circuit in Relation to the Structure of a FET

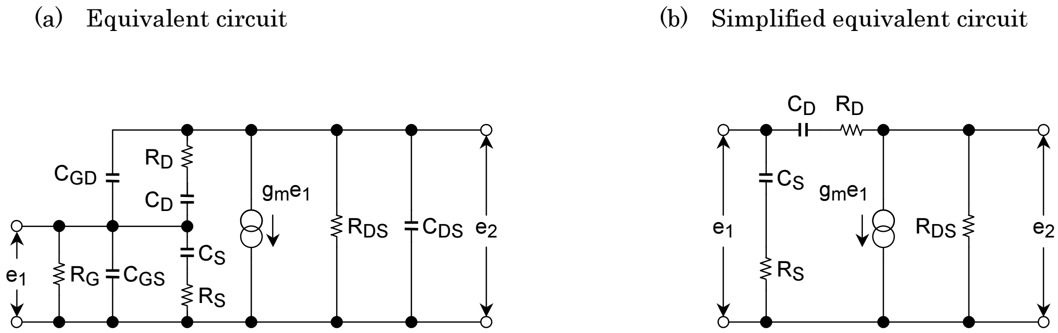


Figure 1.9 Equivalent Circuit

The simplified equivalent circuit can describe the main characteristics of a FET very clearly since it is related to the structure of the FET and is portrayed with basic parameters that do not depend on frequency. For example, here it is understood that DC input resistance (which is infinity) can be in practice ignored and that C_D (internal feedback capacitance) is an unstable factor at high frequency.

Because capacitance can be ignored at low frequency, input resistance $\rightarrow \infty$, and output resistance $\simeq R_{DS}$. With these simplifications this is almost an equivalent circuit of a vacuum tube.

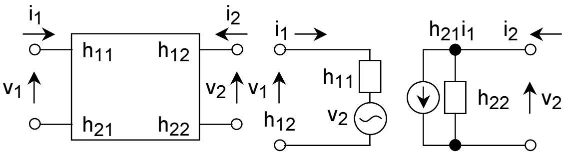
1.2 Circuit Parameters

1.2.1 Matrices Showing the Relations among Inputs and Outputs by Voltage and Current

This is a method used to describe a transistor by regarding it as a four-terminal circuit network, and by using the electrical characteristic of terminals irrespective of the physical characteristics of the transistor.

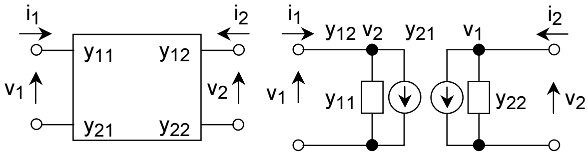
The resulting matrices are of six types, as shown in Table 1.1: the a, b, g, h, y and z matrices. Among these, the “h” and “y” matrices are used comparatively often.

Figure 1.10 and Figure 1.11 show the definitions of “h” and “y” matrices. The common emitter and the common base are differentiated by the use of the suffix e or b after i, r, f, or o.



$$\begin{pmatrix} v_1 \\ i_2 \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix} \begin{pmatrix} i_1 \\ v_2 \end{pmatrix} = \begin{pmatrix} h_i & h_r \\ h_f & h_o \end{pmatrix} \begin{pmatrix} i_1 \\ v_2 \end{pmatrix}$$

Figure 1.10 Circuit Network Depicted by the “h” Matrix



$$\begin{pmatrix} i_1 \\ i_2 \end{pmatrix} = \begin{pmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{pmatrix} \begin{pmatrix} v_1 \\ v_2 \end{pmatrix} = \begin{pmatrix} y_i & y_r \\ y_f & y_o \end{pmatrix} \begin{pmatrix} v_1 \\ v_2 \end{pmatrix}$$

Figure 1.11 Circuit Network Depicted by the “y” Matrix

The physical meanings of each parameter in Figure 1.10 and Figure 1.11 are as follows:

h_i: input impedance

h_r: voltage feedback ratio

h_f: current gain

h_o: output admittance

y_i: input admittance

y_r: reverse transfer admittance

y_f: forward transfer admittance

y_o: output admittance

The “h” matrix is often used for low-frequency regions, and the “y” matrix for radio-frequency regions.

1.2.2 Matrix Showing the Relations among Inputs and Outputs by Power

Such phenomena as the reflection and transfer of waves in a microwave circuit (for example, in waveguides and cavity resonators) are usually indicated by an "S" matrix (scattering matrix).

As the frequency limits for semiconductor products expand, the "S" matrix itself is occasionally used as a circuit parameter.

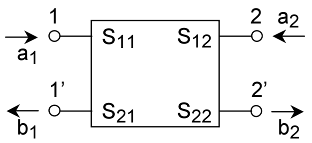
The definition of the "S" matrix is shown in Figure 1.12; the physical meanings of each parameter are as follows:

S_{11}: input reflection coefficient

S_{12}: reverse transfer coefficient

S_{21}: forward transfer coefficient

S_{22}: output reflection coefficient



$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} = \begin{pmatrix} S_i & S_r \\ S_f & S_o \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

Figure 1.12 Circuit Network Depicted by "S" Matrix

The suffix e or b is used to indicate the common emitter or the common base in the same way as for the "h" and "y" parameters.

Table 1.3 Conversion of Parameters

	[H]	[Y]	[S]
[H]	$\begin{matrix} h_i & h_r \\ h_f & h_o \end{matrix}$	$\begin{matrix} \dfrac{1}{y_i} & -\dfrac{y_r}{y_i} \\ \dfrac{y_f}{y_i} & \dfrac{y_i y_o - y_r y_f}{y_i} \end{matrix}$	$\begin{matrix} \dfrac{(1+S_i)(1+S_o)-S_r S_f}{(1-S_i)(1+S_o)+S_r S_f} & \dfrac{2S_r}{(1-S_i)(1+S_o)+S_r S_f} \\ \dfrac{-2S_f}{(1-S_i)(1+S_o)+S_r S_f} & \dfrac{(1-S_o)(1-S_i)-S_r S_f}{(1-S_i)(1+S_o)+S_r S_f} \end{matrix}$
[Y]	$\begin{matrix} \dfrac{1}{h_i} & -\dfrac{h_r}{h_i} \\ \dfrac{h_f}{h_i} & \dfrac{h_i h_o - h_r h_f}{h_i} \end{matrix}$	$\begin{matrix} y_i & y_r \\ y_f & y_o \end{matrix}$	$\begin{matrix} \dfrac{(1+S_o)(1-S_i)+S_r S_f}{(1+S_i)(1+S_o)-S_r S_f} & \dfrac{-2S_r}{(1+S_i)(1+S_o)-S_r S_f} \\ \dfrac{-2S_f}{(1+S_i)(1+S_o)-S_r S_f} & \dfrac{(1+S_i)(1-So)+S_r S_f}{(1+S_i)(1+S_o)-S_r S_f} \end{matrix}$
[S]	$\begin{matrix} \dfrac{(h_i-1)(h_o+1)-h_r h_f}{(h_i+1)(h_o+1)-h_r h_f} & \dfrac{2h_r}{(h_i+1)(h_o+1)-h_r h_f} \\ \dfrac{-2h_f}{(h_i+1)(h_o+1)-h_r h_f} & \dfrac{(1+h_i)(1-h_o)+h_r h_f}{(h_i+1)(h_o+1)-h_r h_f} \end{matrix}$	$\begin{matrix} \dfrac{(1-y_i)(1+y_o)+y_r y_f}{(1+y_i)(1+y_o)-y_r y_f} & \dfrac{-2y_r}{(1+y_i)(1+y_o)-y_r y_f} \\ \dfrac{-2y_f}{(1+y_i)(1+y_o)-y_r y_f} & \dfrac{(1+y_i)(1-y_o)+y_r y_f}{(1+y_i)(1+y_o)-y_r y_f} \end{matrix}$	$\begin{matrix} S_i & S_r \\ S_f & S_o \end{matrix}$

Table 1.4 Conversion Formulas for "h" Parameters

Known "h" Parameters	Converted "h" Parameters: Common Base	Converted "h" Parameters: Common Emitter	Converted "h" Parameters: Common Collector
Common Base		$\begin{matrix} \frac{h_{ib}}{1+h_{fb}} & \frac{\Delta h_b - h_{rb}}{1+h_{fb}} \\ \frac{-h_{fb}}{1+h_{fb}} & \frac{h_{oh}}{1+h_{fb}} \end{matrix}$	$\begin{matrix} \frac{h_{ib}}{1+h_{fb}} & 1 \\ \frac{-1}{1+h_{fb}} & \frac{h_{ob}}{1+h_{fb}} \end{matrix}$
Common Emitter	$\begin{matrix} \frac{h_{ie}}{1+h_{fe}} & \frac{\Delta h_e - h_{re}}{1+h_{fe}} \\ \frac{-h_{fe}}{1+h_{fe}} & \frac{h_{oe}}{1+h_{fe}} \end{matrix}$		$\begin{matrix} h_{ie} & 1 - h_{re} \\ -(1 + h_{fe}) & h_{oe} \end{matrix}$
Common Collector	$\begin{matrix} \frac{-h_{ic}}{h_{fc}} & \frac{-\Delta h_c}{h_{fc}} - 1 \\ \frac{-(1+h_{fc})}{h_{fc}} & \frac{h_{oc}}{h_{fc}} \end{matrix}$	$\begin{matrix} h_{ic} & 1 - h_{rc} \\ -(1 + h_{fc}) & h_{oc} \end{matrix}$	

$\Delta h_e = h_{ie} \cdot h_{oe} - h_{re} \cdot h_{fe}$, $\Delta h_b = h_{ib} \cdot h_{ob} - h_{rb} \cdot h_{fb}$, $\Delta h_c = h_{ic} \cdot h_{oc} - h_{rc} \cdot h_{fe}$

Table 1.5 Conversion Formulas for "y" Parameters

Known "y" Parameters	Converted "y" Parameters: Common Base	Converted "y" Parameters: Common Emitter	Converted "y" Parameters: Common Collector
Common Base		$\begin{matrix} \Sigma y_b & -(y_{rb} + y_{ob}) \\ -(y_{fb} + y_{ob}) & y_{ob} \end{matrix}$	$\begin{matrix} \Sigma y_b & -(y_{ib} + y_{ob}) \\ -(y_{ib} + y_{rb}) & y_{ib} \end{matrix}$
Common Emitter	$\begin{matrix} \Sigma y_e & -(y_{re} + y_{oe}) \\ -(y_{fe} + y_{oe}) & y_{oe} \end{matrix}$		$\begin{matrix} y_{ie} & -(y_{ie} + y_{re}) \\ -(y_{ie} + y_{fe}) & \Sigma y_e \end{matrix}$
Common Collector	$\begin{matrix} y_{oc} & -(y_{fc} + y_{oc}) \\ -(y_{rc} + y_{oc}) & \Sigma y_c \end{matrix}$	$\begin{matrix} y_{ic} & -(y_{ic} + y_{rc}) \\ -(y_{ic} + y_{rc}) & \Sigma y_c \end{matrix}$	

$\Sigma y_e = y_{ie} + y_{re} + y_{fe} + y_{oe}$

$\Sigma y_b = y_{ib} + y_{rb} + y_{fb} + y_{ob}$

$\Sigma y_c = y_{ic} + y_{rc} + y_{fc} + y_{oc}$

Table 1.6 "h" Parameters Converted by Early T-Type Device Parameters

	Common Base		Common Emitter
h_{ib}	$\dfrac{r_e + r_{bb'}\left((1-\alpha_0)+j\dfrac{f}{f_\alpha}\right)}{1+j(f/f_\alpha)}$	h_{ie}	$r_{bb'}+\dfrac{r_e}{(1-\alpha_0)+j(f/f_\alpha)}$
h_{rb}	$j2\pi fC_c r_{bb'}$	h_{re}	$2\pi f_\alpha C_c r_e \dfrac{j\dfrac{f}{f_\alpha}}{(1-\alpha_0)+j(f/f_\alpha)}$
h_{fb}	$\dfrac{-\alpha_0}{1+j(f/f_\alpha)}$	h_{fe}	$\dfrac{\alpha_0}{(1-\alpha_0)+j(f/f_\alpha)}$
h_{ob}	$j2\pi fC_c$	h_{oe}	$2\pi f_\alpha C_c \dfrac{j\dfrac{f}{f_\alpha}\left(1+j\dfrac{f}{f_\alpha}\right)}{(1-\alpha_0)+j(f/f_\alpha)}$

Table 1.7 "y" Parameters Converted by Early T-Type Device Parameters

	Common Base		Common Emitter
y_{ib}	$\dfrac{1+j\dfrac{f}{f_\alpha}}{r_e + jr_{bb'}\dfrac{f}{f_\alpha}}$	y_{ie}	$\dfrac{(1-\alpha_0)+j\dfrac{f}{f_\alpha}}{r_e + jr_{bb'}\dfrac{f}{f_\alpha}}$
y_{rb}	$-2\pi f_\alpha C_c \dfrac{j\dfrac{f}{f_\alpha}\left(1+j\dfrac{f}{f_\alpha}\right)}{\dfrac{r_e}{r_{bb'}}+j\dfrac{f}{f_\alpha}}$	y_{re}	$-2\pi f_\alpha C_c \dfrac{r_e}{r_{bb'}} \dfrac{j\dfrac{f}{f_\alpha}}{\dfrac{r_e}{r_{bb'}}+j\dfrac{f}{f_\alpha}}$
y_{fb}	$-\dfrac{\alpha_0}{r_e + jr_{bb'}\dfrac{f}{f_\alpha}}$	y_{fe}	$\dfrac{\alpha_0}{r_e + jr_{bb'}\dfrac{f}{f_\alpha}}$
y_{ob}	$2\pi f_\alpha C_c \dfrac{j\dfrac{f}{f_\alpha}\left(1+\dfrac{r_e}{r_{bb'}}+j\dfrac{f}{f_\alpha}\right)}{\dfrac{r_e}{r_{bb'}}+j\dfrac{f}{f_\alpha}}$	y_{oe}	$2\pi f_\alpha C_c \dfrac{j\dfrac{f}{f_\alpha}\left(1+\dfrac{r_e}{r_{bb'}}+j\dfrac{f}{f_\alpha}\right)}{\dfrac{r_e}{r_{bb'}}+j\dfrac{f}{f_\alpha}}$

Note: The common base parameter y_{ob} and the common emitter parameter y_{oe} are identical.

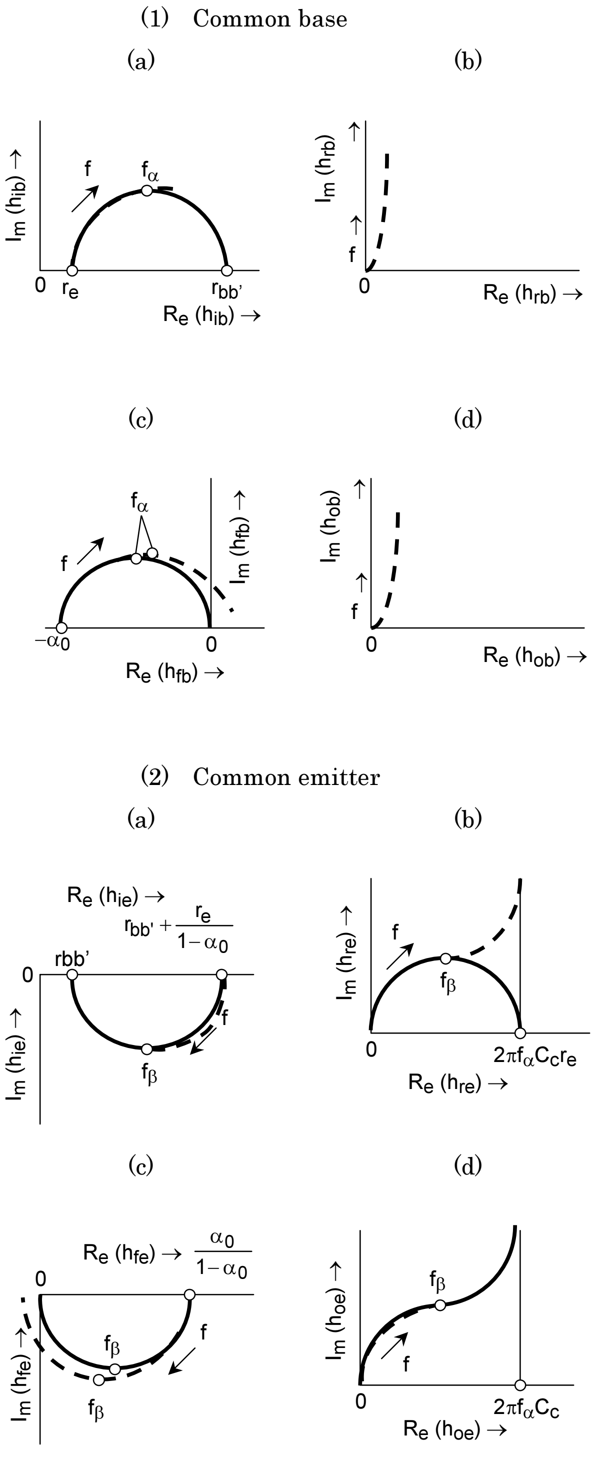


Figure 1.13 Frequency Locus of "h" Parameters

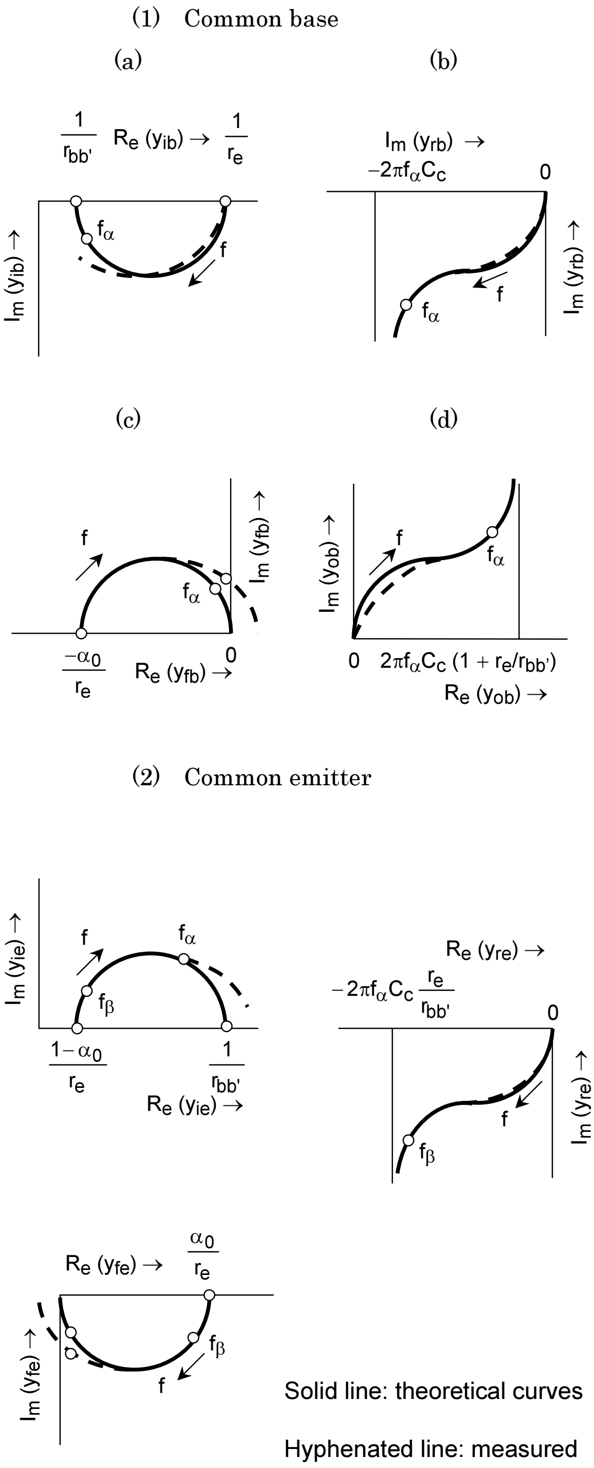


Figure 1.14 Frequency Locus of "y" Parameters

Refer to Table 1.3, Table 1.4, and Table 1.5 for the correlation and conversion among circuit parameters of the common base and common emitter. Figure 1.13 and Figure 1.14 show the frequency locuses of "h" and "y" parameters obtained from Table 1.6 and Table 1.7.

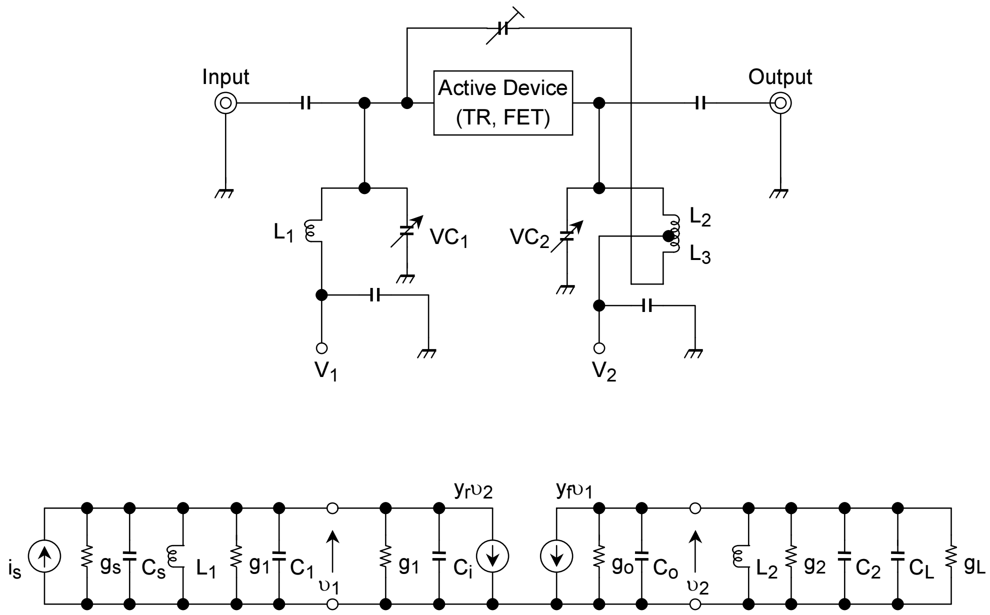
The above parameters vary according to the operating points and temperature, and circuit designers should allow for such variations.

2. Gain and Stability

Figure 2.1 shows the basic radio-frequency amplification circuit of a transistor/FET and the FET's equivalent circuit.

When this amplification circuit is tuned to the center frequency, the capacitance is removed and only the conductance remains, as shown in the equivalent circuit in Figure 2.2.

In this circuit, if both the capacitance and the conductance are neutralized, it can be assumed that $|yr| \simeq 0$. The same assumption that $|yr| \simeq 0$ can also be made for active devices with small reverse transfer capacitance, such as cascaded FETs. Also, when the unloaded Q in the I/O coil is large, and when the loss conductances g_1 and g_2 are ignored, a circuit of simple configuration can be constructed as shown in Figure 2.3.



i_s: constant signal current source

g_s, C_s: signal source conductance, capacitance

g_i, C_i: input conductance, capacitance

L_1, L_2: I/O tuning inductance

g_o, C_o: output conductance, capacitance

g_1, g_2: power loss conductance of an I/O coil

g_L, C_L: load conductance, capacitance

C_1, C_2: load conductance in external I/O

Figure 2.1 Basic Radio-Frequency Amplifier Circuit and its Equivalent Circuit

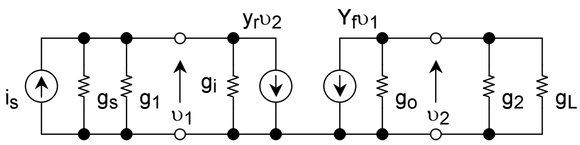


Figure 2.2 Equivalent Circuit (tuned frequency)

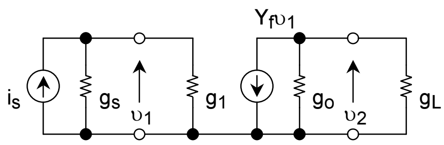


Figure 2.3 Unidirectional Equivalent Circuit

We now find the power gain of the equivalent circuit.

$$G_p = \frac{P_o}{P_i\ (max)} = \frac{|\upsilon_2|^2 g_L}{|i_s|^2/4g_s} \quad \cdots\cdots (1)$$

Combining this with

$$\upsilon_2 = \frac{yf\,\upsilon_1}{g_o + g_L},\ i_s = -\upsilon_1(g_s + g_i)$$

we obtain

$$G_p = \frac{4\,|y_f|^2 g_s g_L}{(g_s + g_i)^2 (g_o + g_L)^2} \quad \cdots\cdots (2)$$

When $g_s = g_i$ and $g_L = g_o$, the power gain becomes maximum; these conditions are met when the input and the output are matched.

$$G_p(max) = \frac{|y_{fs}|^2}{4g_i g_o} \quad \cdots\cdots (3)$$

Gp (max) is the Maximum Available Gain (MAG) that can be achieved when the circuit and device impedance are matched at both the input and output interfaces, while input-to-output signal transfer is unidirectional.

Therefore, in practice, stability gain must be considered as well as power gain.

The active device stability coefficient s is

$$S = \frac{2g_i \cdot g_o}{1 + \cos(\phi_r + \phi_f)\,|y_r| \cdot |y_f|} \quad \cdots\cdots (4)$$

Where ϕ is the phase angle of the “y” parameter,

$$\begin{cases} \phi_r = \tan^{-1}(b_r/g_r) \\ \phi_f = \tan^{-1}(b_f/g_f). \end{cases}$$

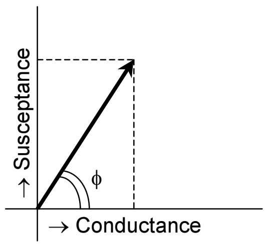


Figure 2.4 Phase Angle Diagram

The stability coefficient is calculated from the "y" parameter of the device; and, if s > 1, the device can be deemed stable without the I/O circuit being taken into account. However, when s ≤ 1, there is a danger that the I/O circuit may cause oscillation.

In a radio-frequency amplifier circuit, total stability S is expressed in terms of Gi and Go.

$$S = \frac{2}{1+\cos(\phi_r+\phi_f)} \cdot \frac{G_i \cdot G_o}{|y_r||y_f|} \quad \text{.......... (5)}$$

Where $G_i = g_s + g_1 + g_i$

$G_0 = g_0 + g_2 + g_L$.

The relationship between S and the stability coefficient of a device (s) can be expressed as follows:

$$S = \frac{G_i G_o}{g_i g_o} \cdot s$$

$$= \left(1+\frac{g_s+g_1}{g_1}\right)\left(1+\frac{g_L+g_2}{g_o}\right) \cdot s \quad \text{.......... (6)}$$

$S \geq s$

In other words, the circuit stability can be increased by selecting a larger g_s, g_L, g_1, or g_2.

When the input and output are matched, even though the loss conductance of the coil is $(g_1, g_2) = 0$,

$$\begin{cases} G_i = g_s + g_i = 2g_i \\ G_o = g_o + g_L = 2g_o \end{cases}$$

$S = 4\ s$

and total circuit stability four times greater than that of the device alone can be attained.

Power gain G_p can be expressed as a function of S:

$$G_p = \frac{1}{S} \cdot \frac{2}{1+\cos(\phi_r+\phi_f)} \cdot \frac{|y_f|}{|y_f|} \quad \text{.......... (7)}$$

This formula can be changed to

$$G_p = \frac{4}{S} \cdot \frac{2}{1+\cos(\phi_r+\phi_f)} \cdot \frac{g_i \cdot g_o}{|y_r||y_f|} \cdot \frac{|y_f|^2}{4g_i g_o} \quad \text{.......... (8)}$$

$$= \frac{4s}{S} \cdot G_p(\max) \quad \text{.......... (9)}$$

An S value of at least 4 (S ≥ 4) indicates good circuit stability.

$G_p \leq s \cdot G_p\ (\max)$ .... (10)

If S ≤ 1, indicating poor device stability, the MAG of the device is the upper limit of the power gain which can be attained in the circuit.

Table 2.1 shows MAG and the G_p of a radio-frequency transistor/FET when S = 4.

Table 2.1 Gain and Stability (example)

f = 100 MHz

		MAG (dB)	s	G_{ps} (dB)
TR	2SC1923	34.9	0.030	19.6
J-FET	2SK192A	26.9	0.023	10.5
	2SK161	26.4	0.265	20.7
MOSFET	2SK241	34.0	0.120	24.8

Several methods are available for achieving stable gain in radio-frequency circuits. The most popular circuit-design-based method is to avoid feedback by installing a neutralized circuit. Figure 2.5 shows an example.

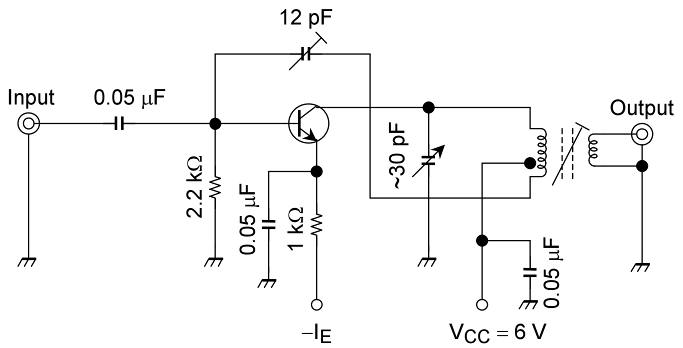


Figure 2.5 2SC380TM 10.7 MHz Amplifier Circuit

Another method is to lower the feedback capacitance by means of a cascode connection.
Figure 2.6 shows a typical example of a cascode-connected circuit.

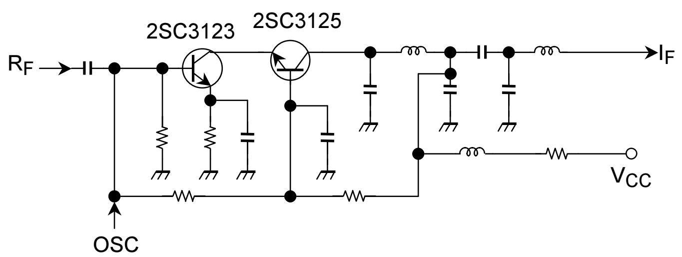


Figure 2.6 TV Tuner VHF Mixer Circuit

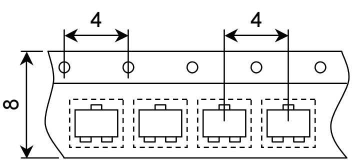
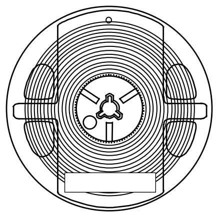
The Faraday shield (electrostatic screen) method is used to protect transistors from interference generated by other active devices.

In the case of FETs, the construction of devices with internal cascode connections, such as cascode FETs and dual MOSFETs, is equivalent to the Faraday shield method.

3. Tape Packing Specifications

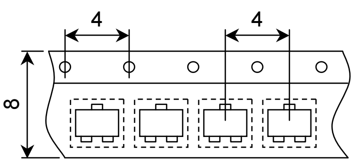
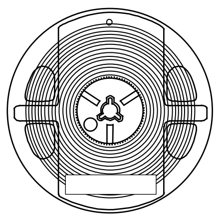
3.1 Tape Specifications by Type of Device Package

3.1.1
- ○ Super-Mini Package Group: S-MINI, SMQ, SMV (SSOP5-P-0.95) and SM6 (SSOP6-P-0.95)
- ○ Ultra-Super-Mini Package Group: USM, USQ, USV US6
- ○ Small Super-Mini (SSM)
- ○ Thin Extreme-Super-Mini Package (TESM)
- ○ Thin Ultra-Super-Mini 6 pin Package (TU6)

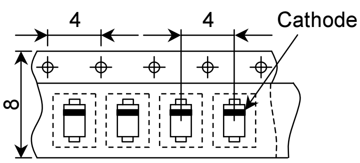
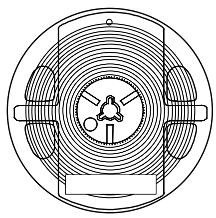
<table>
<tr><th>Packing Type</th><th>Tape Type Suffix</th><th>Tape Dimensions (Unit: mm)</th><th>Reel Appearance</th><th>Packing Quantity</th></tr>
<tr><td rowspan="2">Embossed tape</td><td>TE85L</td><td rowspan="2"></td><td rowspan="2"></td><td>3000 per reel (Note 1)</td></tr>
<tr><td>TE85L2 (only for s-mini, SMV and USM)</td><td>10000 per reel</td></tr>
</table>

Note 1: TESM: 4000 per reel.

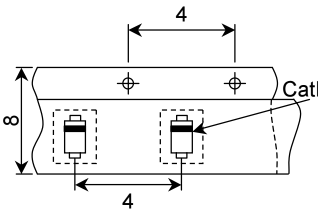
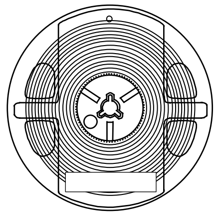
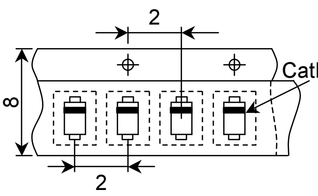
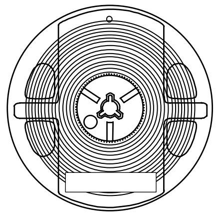
3.1.2 Super-Mini Package for Varicap Diode

<table>
<tr><th>Packing Type</th><th>Tape Type Suffix</th><th>Tape Dimensions (Unit: mm)</th><th>Reel Appearance</th><th>Pair</th><th>Packing Quantity</th></tr>
<tr><td rowspan="5">Embossed tape</td><td>TPH2</td><td rowspan="5"></td><td rowspan="5"></td><td>○</td><td rowspan="3">3000 per reel</td></tr>
<tr><td>TPH3</td><td>×</td></tr>
<tr><td>TPH4</td><td>○</td></tr>
<tr><td>TPH6</td><td>○</td><td>600 to 3000 per reel</td></tr>
<tr><td>TPH7</td><td>○</td><td>3000 per reel</td></tr>
</table>

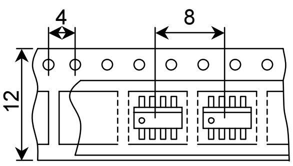
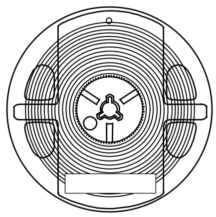
3.1.3 Ultra-Super-Mini Coaxial Package (USC)

<table>
<tr><th>Packing Type</th><th>Tape Type Suffix</th><th>Tape Dimensions (Unit: mm)</th><th>Reel Appearance</th><th>Pair</th><th>Packing Quantity</th></tr>
<tr><td rowspan="3">Embossed tape</td><td>TPH2</td><td rowspan="3"></td><td rowspan="3"></td><td>○</td><td>2400 to 3000 per reel</td></tr>
<tr><td>TPH3</td><td>×</td><td>3000 per reel</td></tr>
<tr><td>TPH4</td><td>○</td><td>2400 to 3000 per reel</td></tr>
</table>

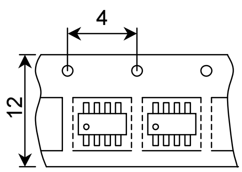
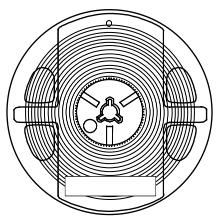
3.1.4 Extreme-Super-Mini Coaxial Package (ESC)
Thin Extreme-Super-Mini Coaxial Package (TESC)

Packing Type	Tape Type Suffix	Tape Dimensions (Unit: mm)	Reel Appearance	Pair	Packing Quantity
Embossed tape	TPH2			○	3200 to 4000 per reel
	TPH3			×	4000 per reel
	TPL2			○	6400 to 8000 per reel
	TPL3			×	8000 per reel

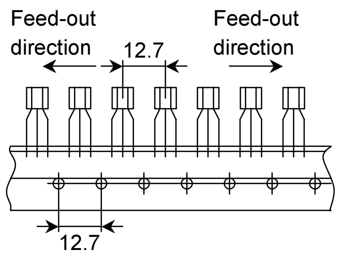
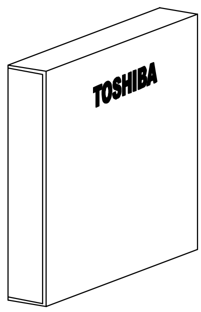
3.1.5 Flat-Mini Package (FM8)

Packing Type	Tape Type Suffix	Tape Dimensions (Unit: mm)	Reel Appearance	Packing Quantity
Embossed tape	TE12L			1000 per reel

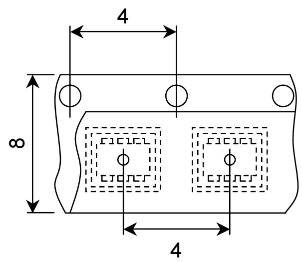
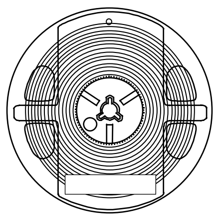
3.1.6 Flat-Super-Mini Package (SM8) (SSOP8-P-0.65)

Packing Type	Tape Type Suffix	Tape Dimensions (Unit: mm)	Reel Appearance	Packing Quantity
Embossed tape	TE12L			3000 per reel

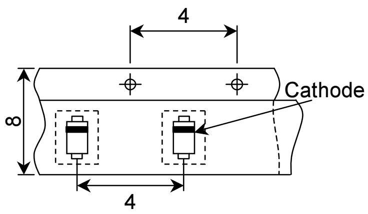
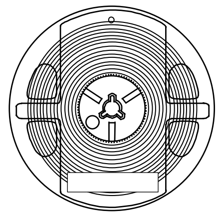
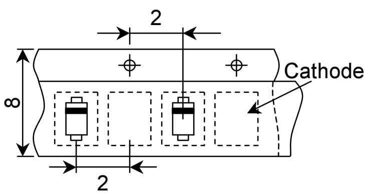
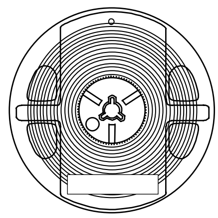
3.1.7 Mini Package (MINI)

Packing Type	Tape Type Suffix	Tape Dimensions (Unit: mm)	Reel Appearance	Packing Quantity
Ammo pack	TPE4			5000 per carton

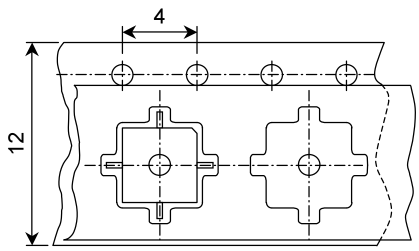
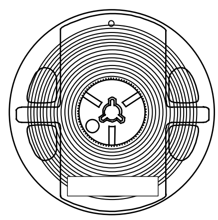
3.1.8 Extreme-Super-Mini 6 pin Package (ES6)
Small Extreme-Super-Mini 6 pin Package (sES6)

Packing Type	Tape Type Suffix	Tape Dimensions (Unit: mm)	Reel Appearance	Packing Quantity
Embossed tape	TE85L			4000 per reel

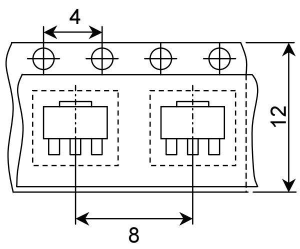
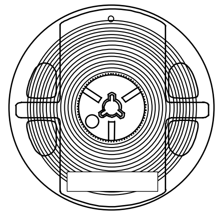
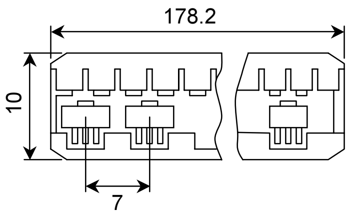
3.1.9 Small Extreme-Super-Mini Coaxial Package (sESC)

Packing Type	Tape Type Suffix	Tape Dimensions (Unit: mm)	Reel Appearance	Pair	Packing Quantity
Embossed tape	TPH3			×	5000 per reel
	TPL3			×	10000 per reel

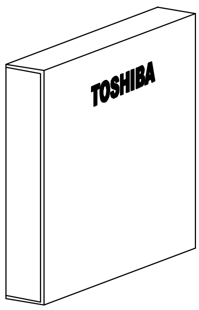
3.1.10 PW-X Package

Packing Type	Tape Type Suffix	Tape Dimensions (Unit: mm)	Reel Appearance	Packing Quantity
Embossed tape	TE12L			1000 per reel

3.1.11 Power Mini Transistor Package (PW-MINI)

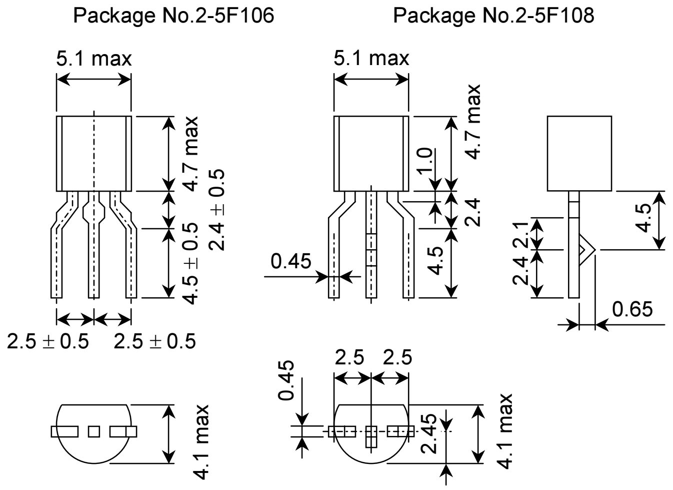
Packing Type		Tape Type Suffix	Tape Dimensions (Unit: mm)	Reel Appearance	Packing Quantity
Tape	Pack type	TE12L			1000 per reel
Magazine	Stick type	—			25 per magazine

3.1.12 TO-92/Mini Devices

Tape Type Suffix	Applied Package Type	Packing Type	Packing Quantity	Reel Appearance
TPE2	TO-92 (2-5F)	Ammo pack	3000 pcs	
TPE4	MINI (2-4E)	Ammo pack	5000 pcs	

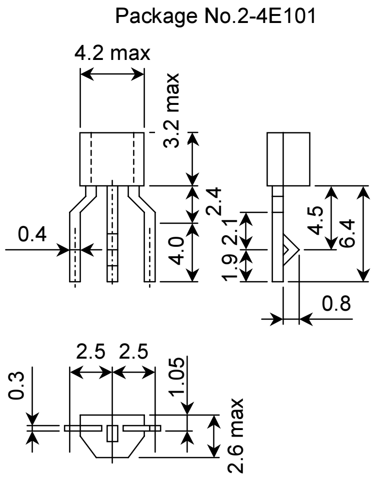
3.2 Lead Formed TO-92 and Mini Transistor Package Dimensions

Unit: mm



Snap forming: center lead

Figure 3.1 Lead-Formed TO-92 Transistor Package Dimensions



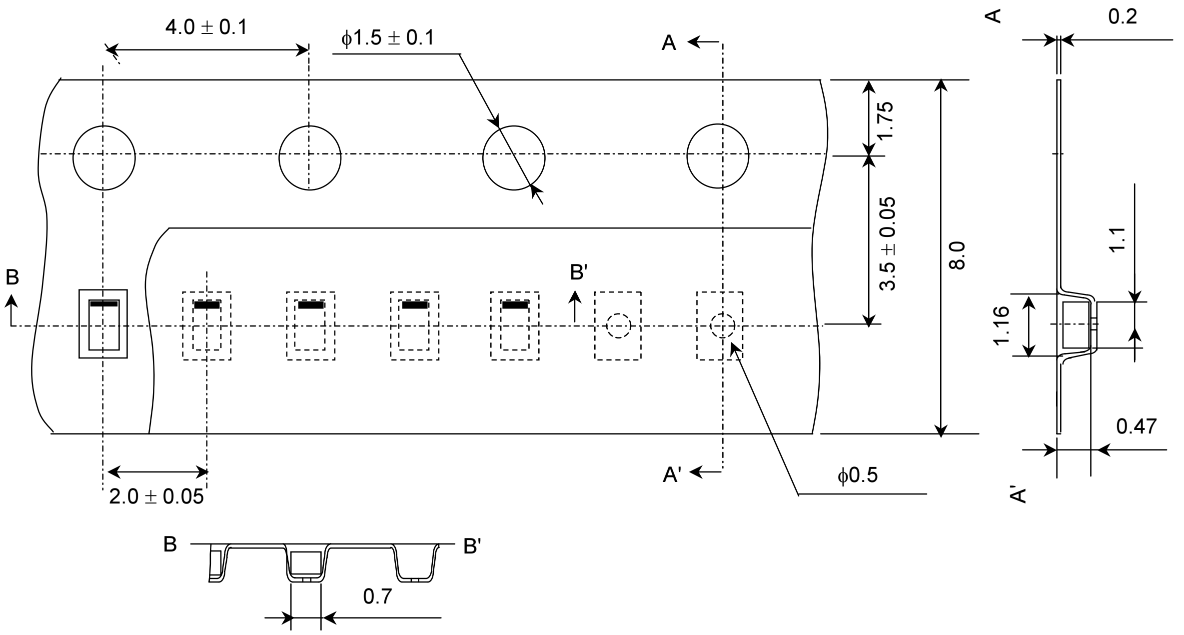
Snap forming: center lead

Figure 3.2 Lead-Formed Mini Transistor Package Dimensions

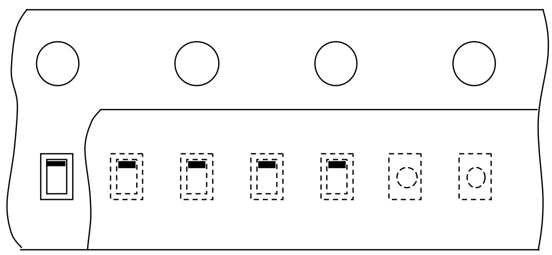
3.3 Tape Dimensions

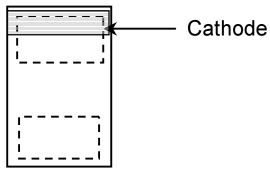
3.3.1 Tape Layout for Chip Scale Package Thin Type 2 Pin…(CST2)

Unit: mm



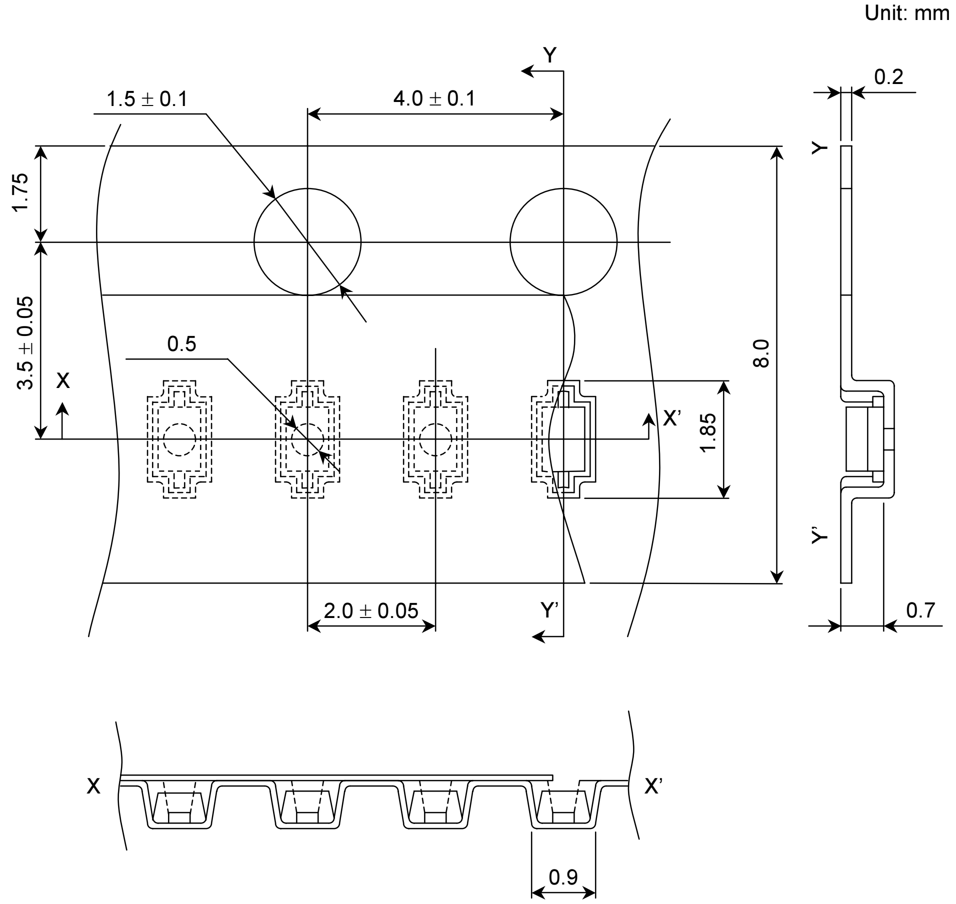
Device orientation

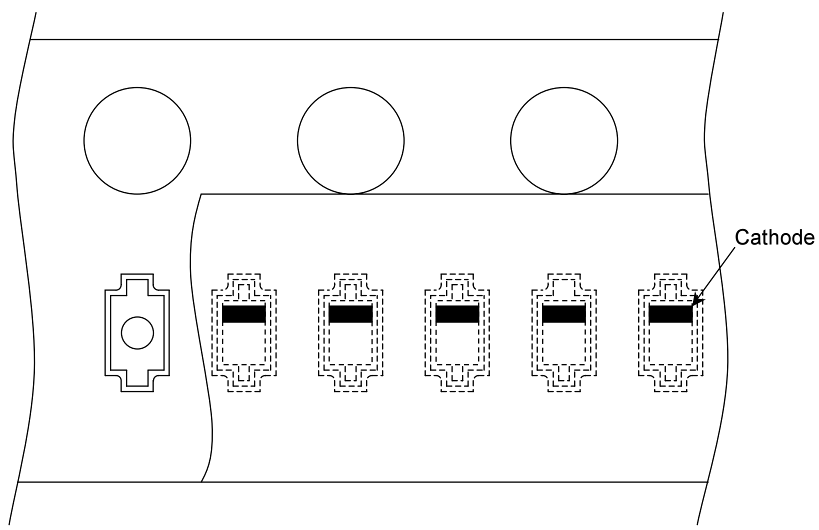




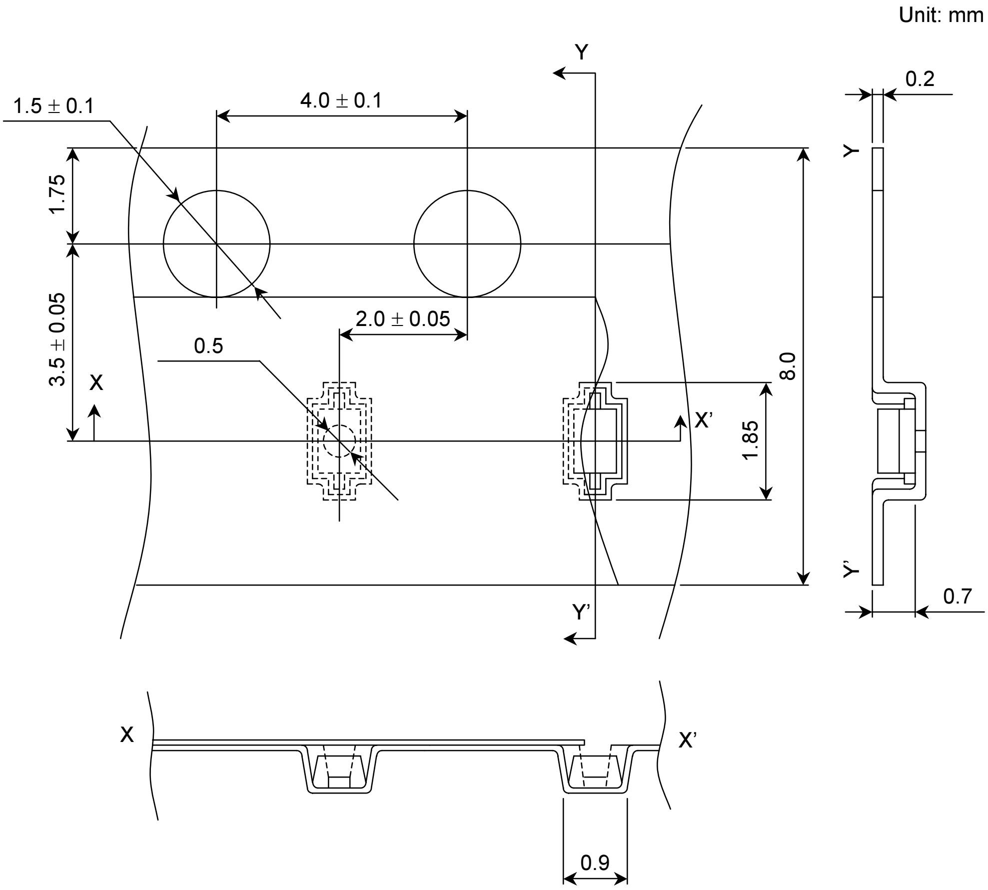
3.3.2 Tape Layout for Extreme-Super-Mini Coaxial…(ESC)
Tape Layout for Thin Extreme-Super-Mini Coaxial…(TESC)

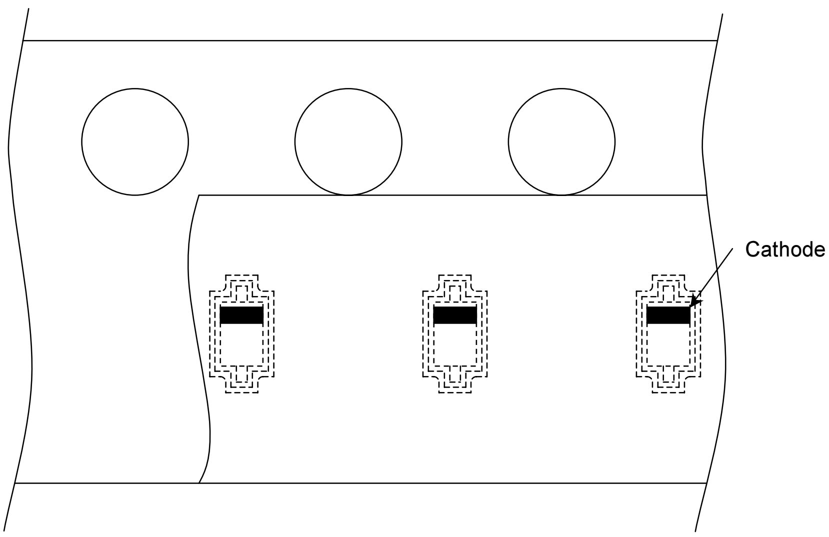
2 mm Pitch Type





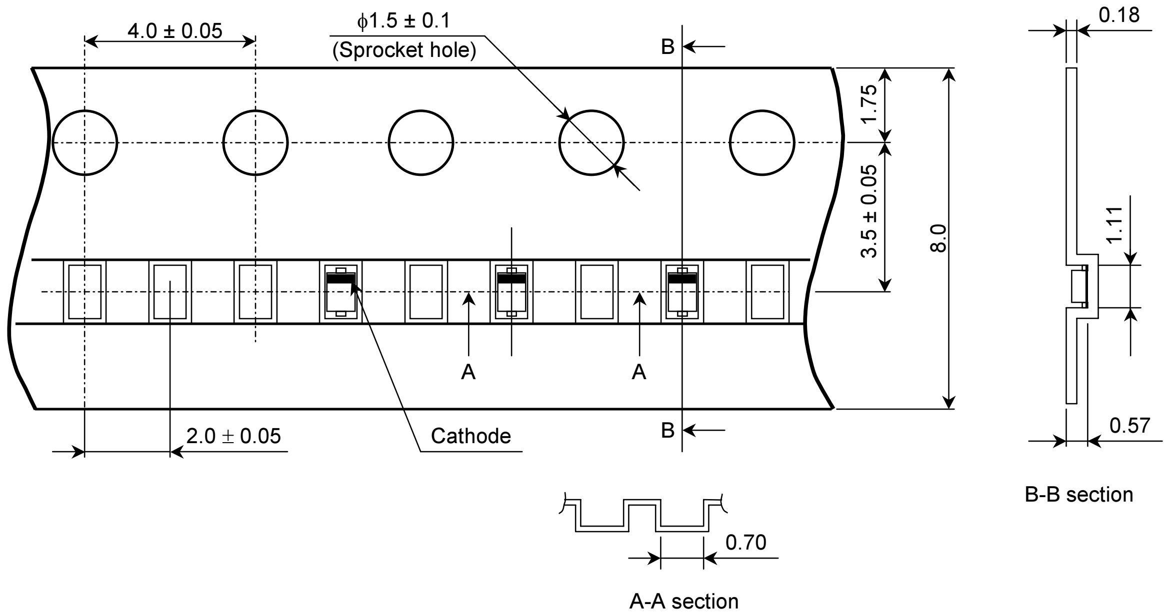
4 mm Pitch Type



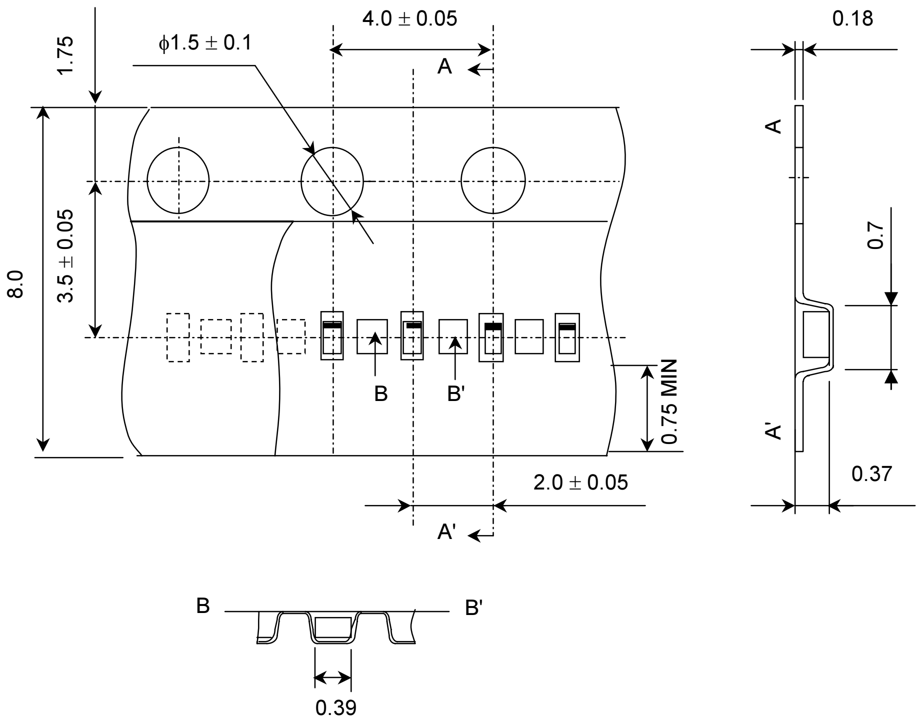


3.3.3 Tape Layout for Fine Pitch Super-Mini Coaxial…(fSC)

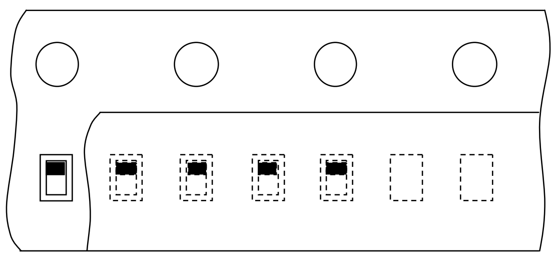
Unit: mm

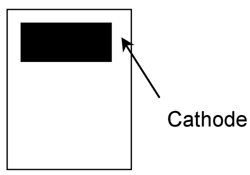


3.3.4 Tape Layout for Small Chip Scale Package 2 Pin…(SC2)



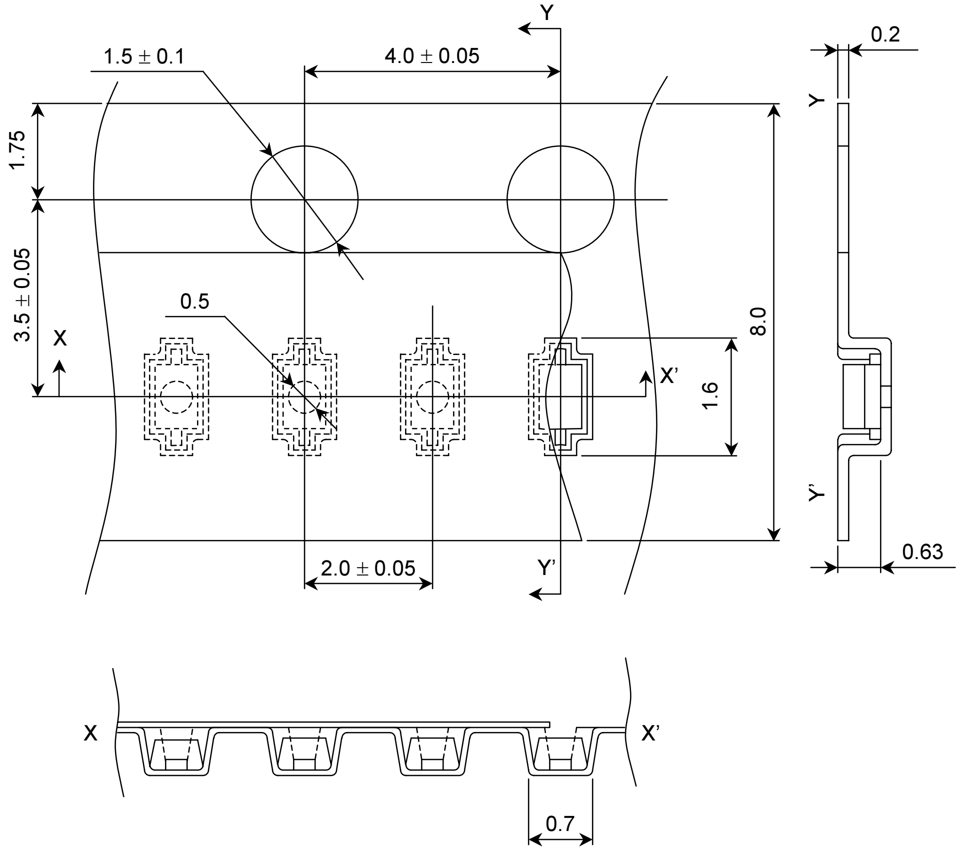
Device orientation

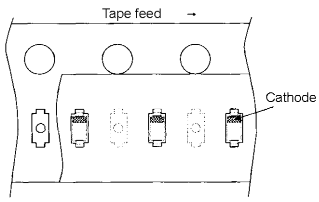




3.3.5 Tape Layout for Small-Extreme-Super-Mini Coaxial…(sESC)

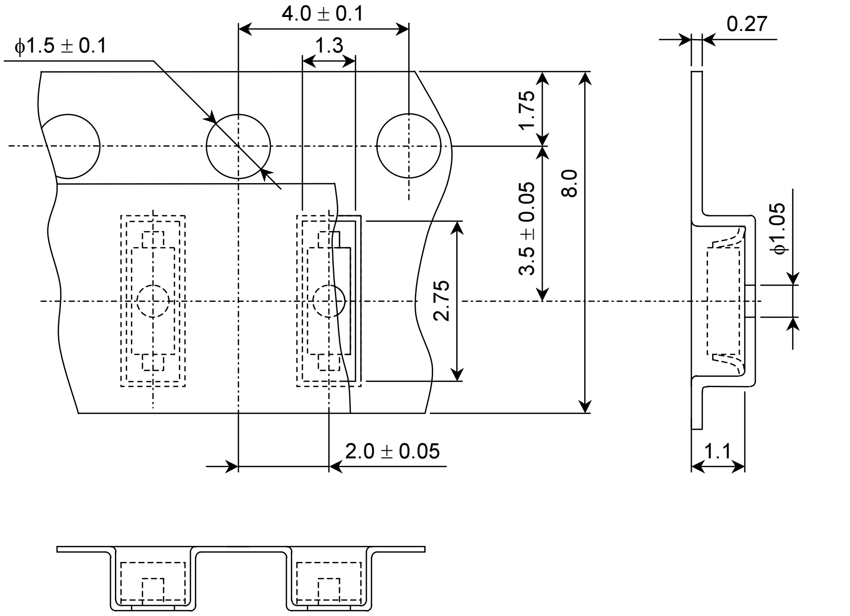
Unit: mm



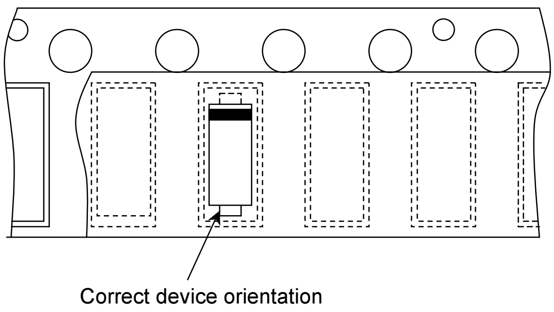


3.3.6 Tape Layout for Ultra-Super-Mini Coaxial…(USC)

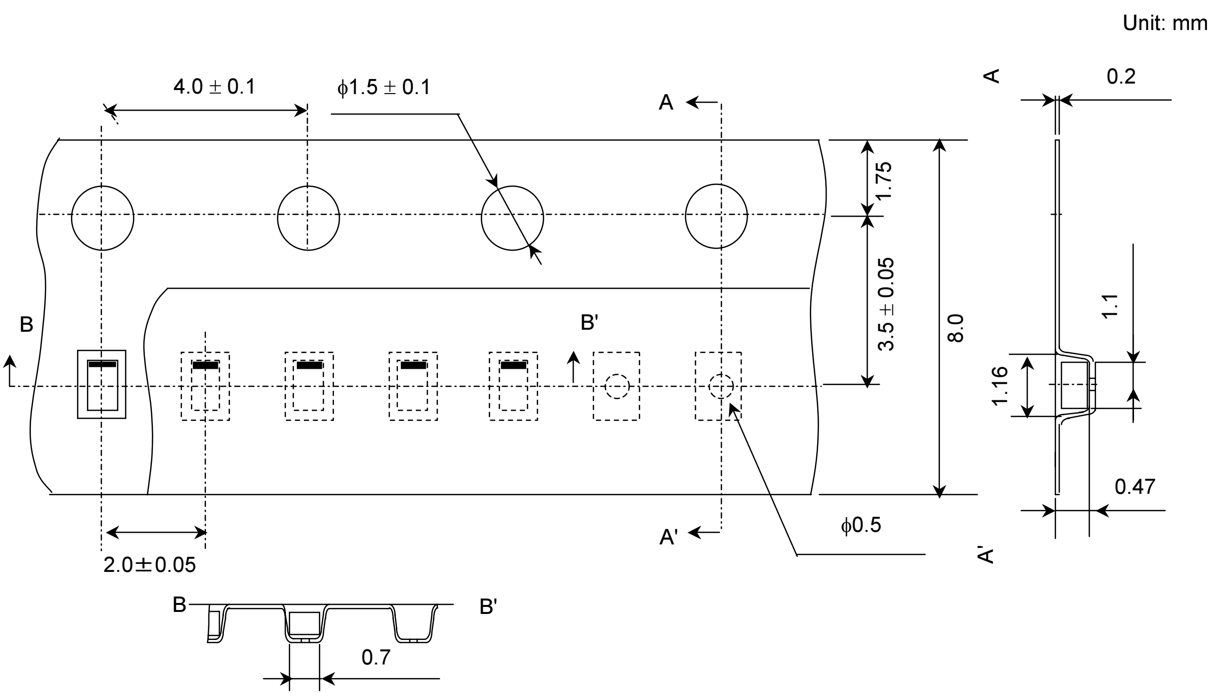
Unit: mm



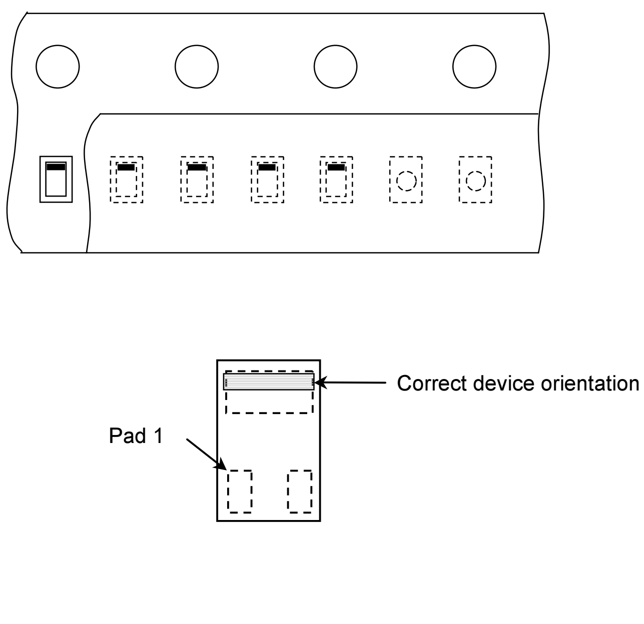
Device orientation



3.3.7 Tape Layout for Chip-Scale Package Thin Type 3 Pin…(CST3)

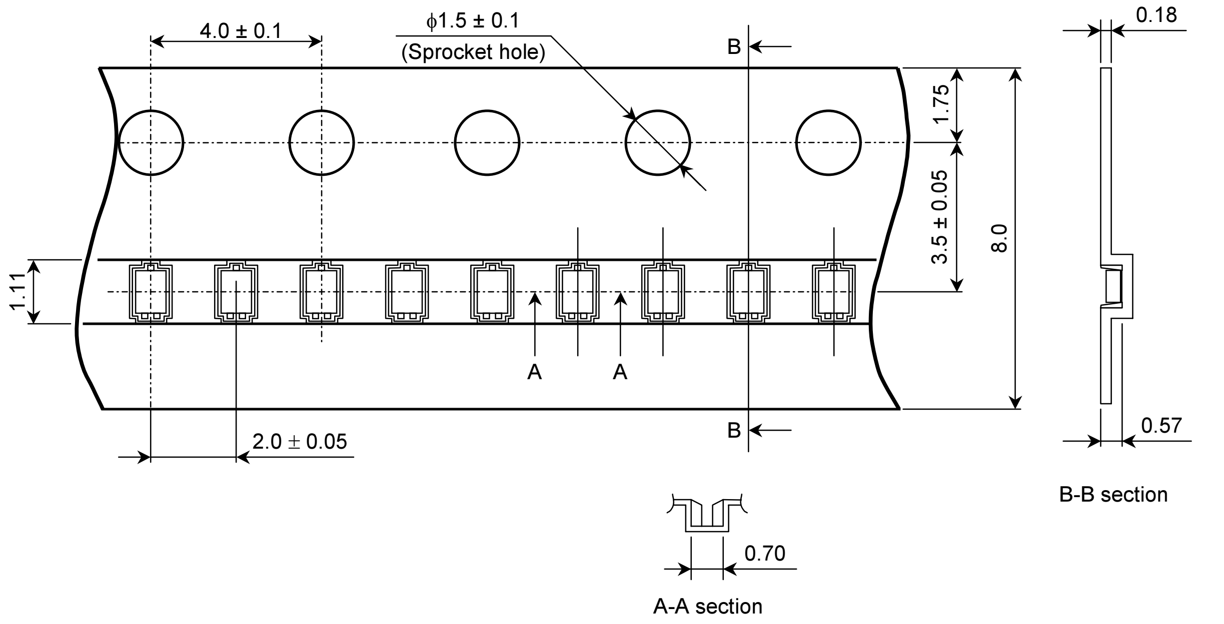


Device orientation



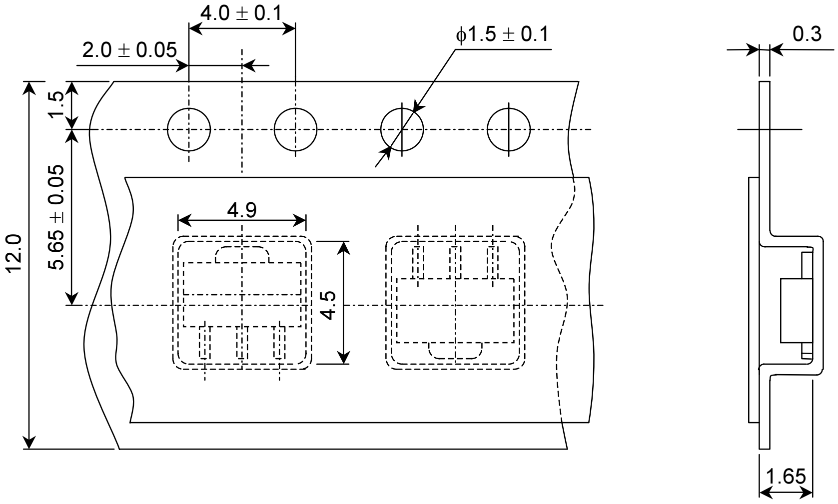
3.3.8 Tape Layout for Fine Pitch Super-Mini Mold…(fSM)

Unit: mm

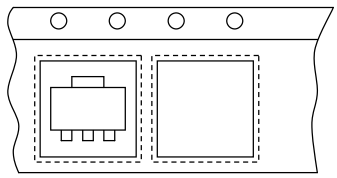


3.3.9 Tape Layout for Power Mini…(PW-MINI)

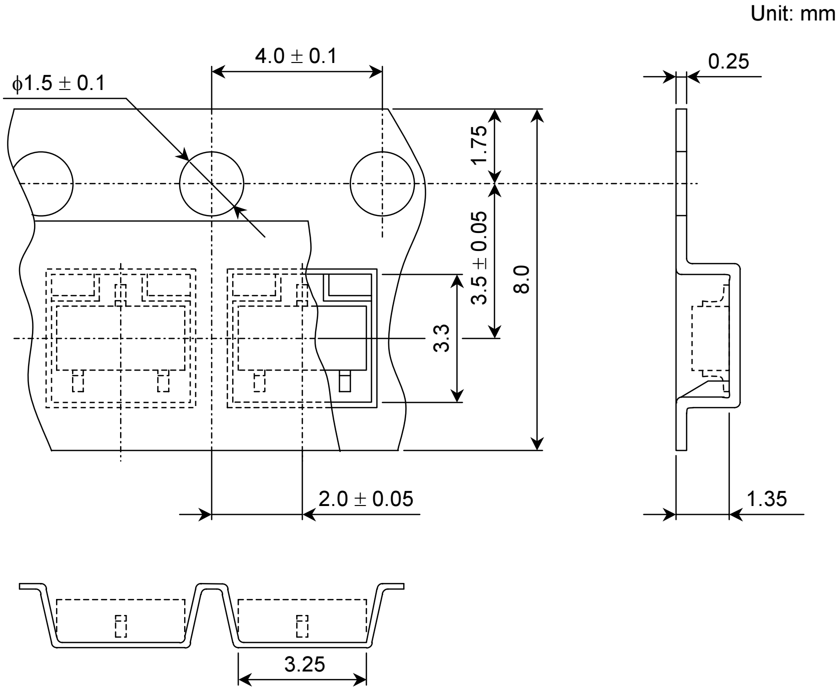
Unit: mm



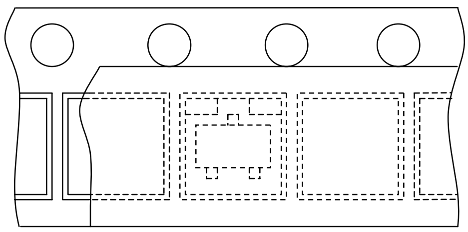
Device orientation



3.3.10 Tape Layout for Super-Mini…(S-MINI)

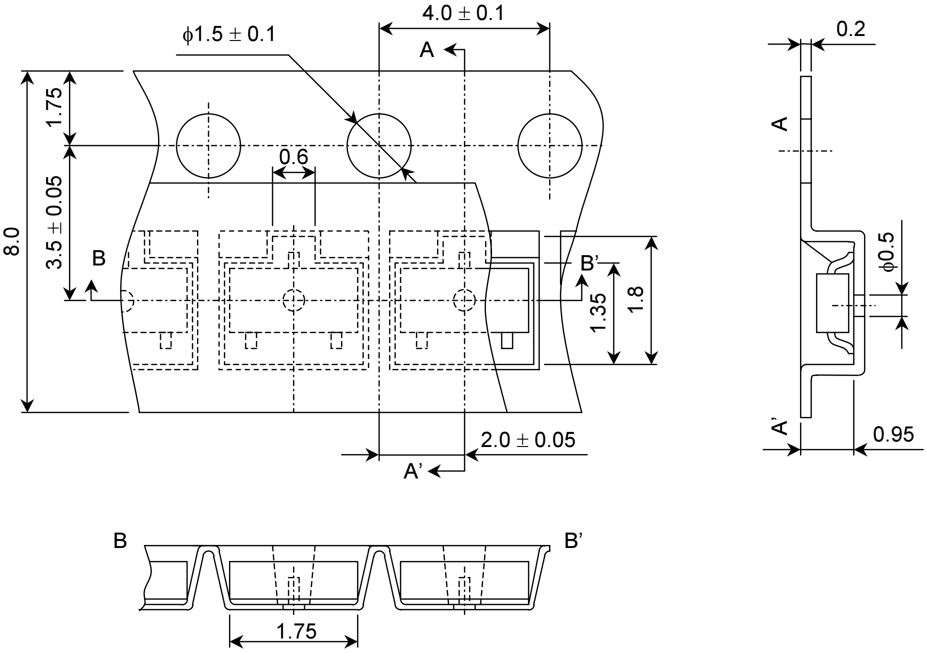


Device orientation

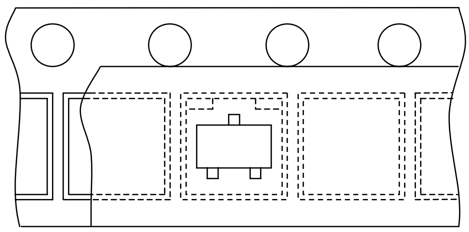


3.3.11 Tape Layout for Small-Super-Mini…(SSM)

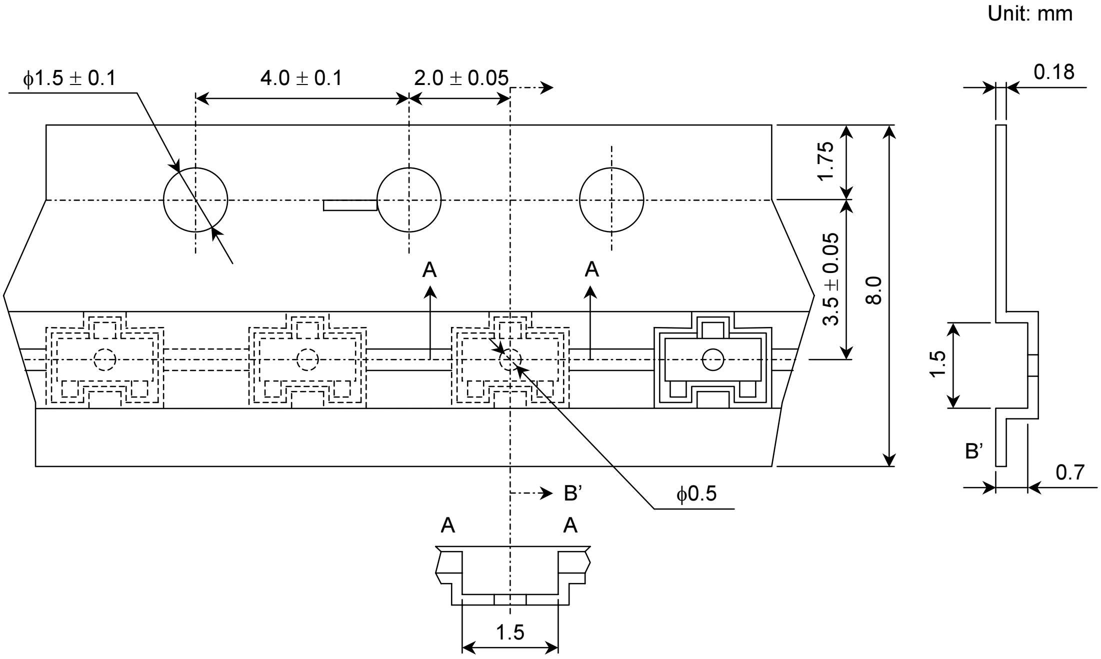
Unit: mm



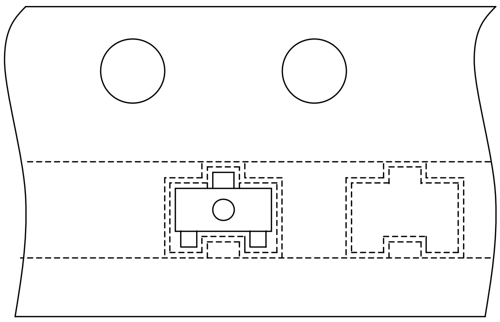
Device orientation



3.3.12 Tape Layout for Thin-Extreme-Super-Mini…(TESM)

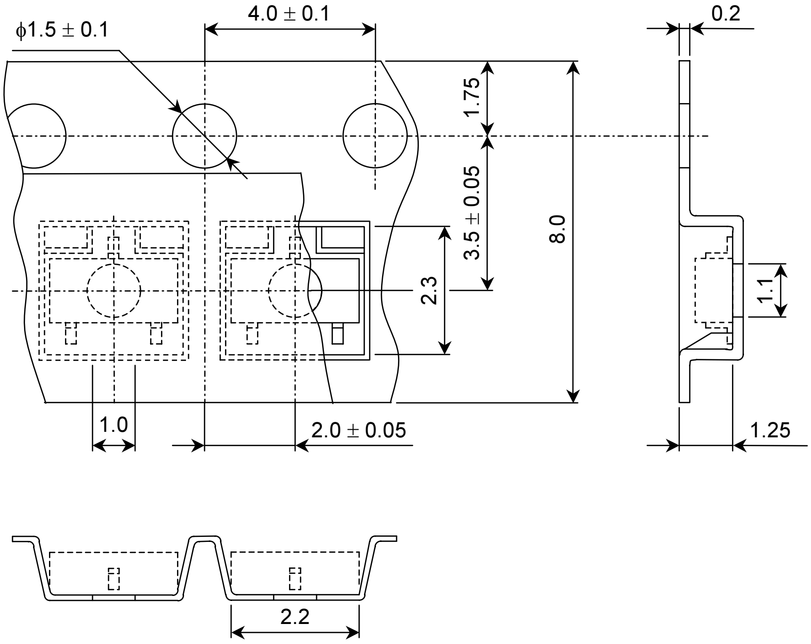


Device orientation

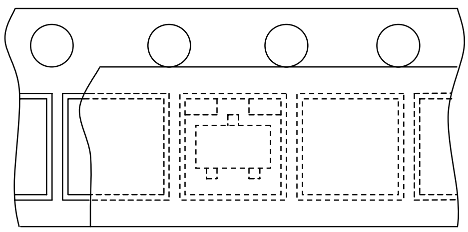


3.3.13 Tape Layout for Ultra-Super-Mini…(USM)

Unit: mm

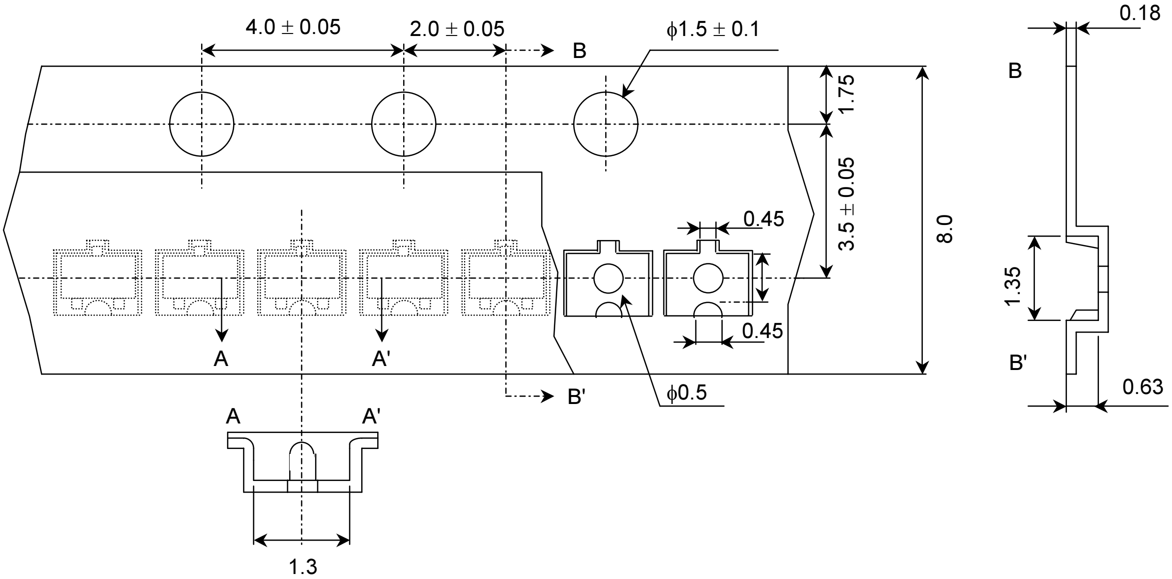


Device orientation

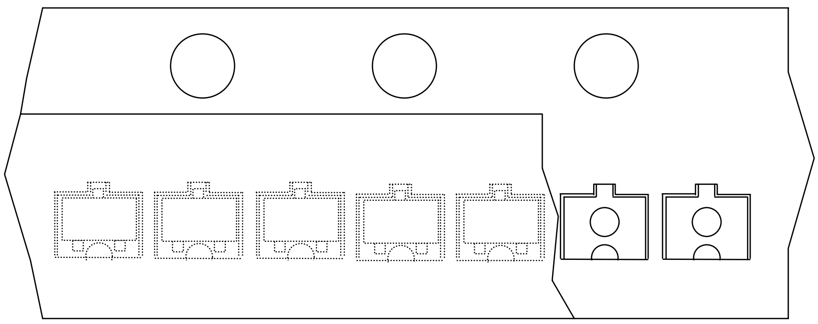


3.3.14 Tape Layout for Very Thin Extreme-Super-Mini…(VESM)

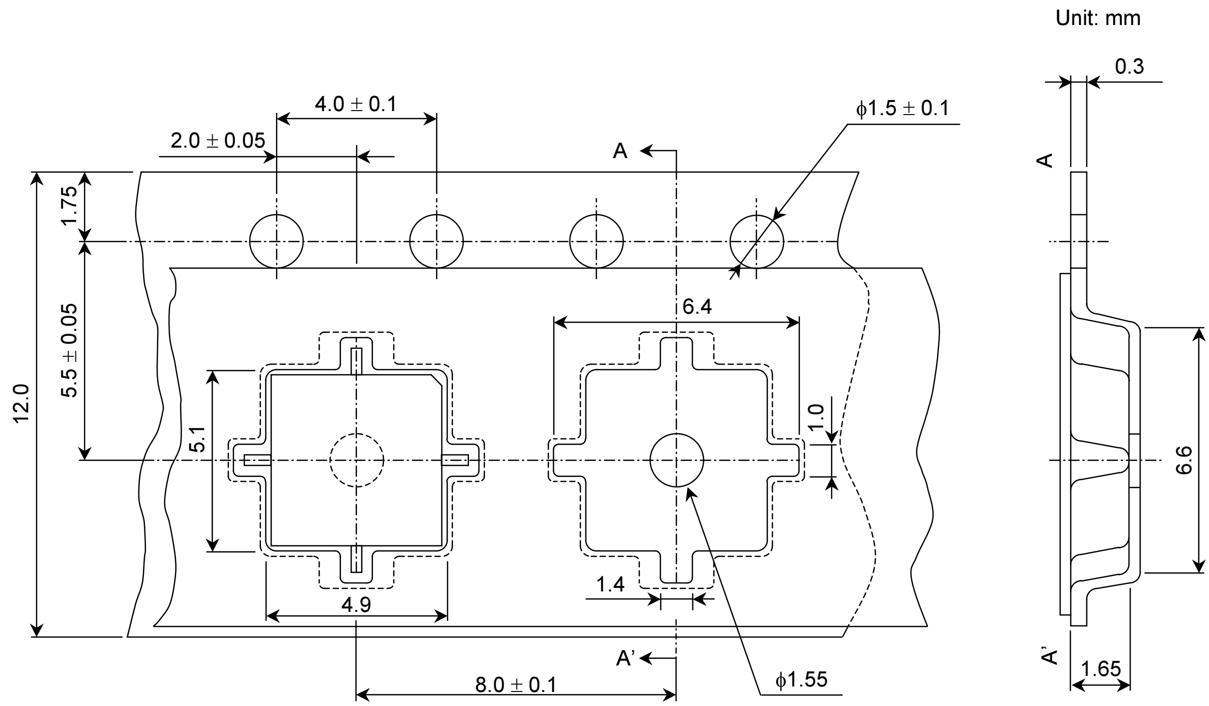
Unit: mm

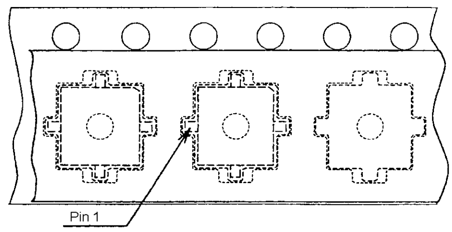


Device orientation

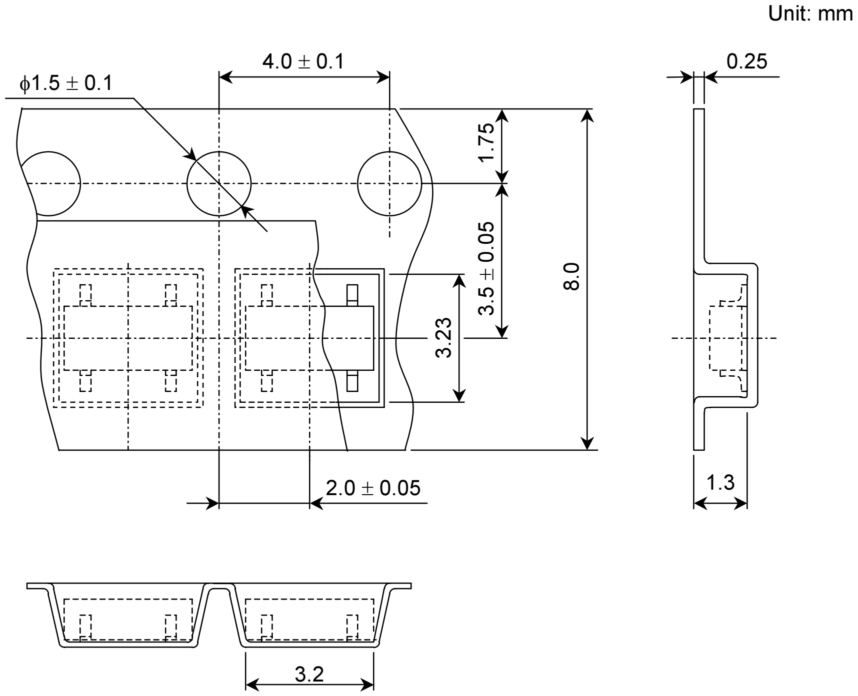


3.3.15 Tape Layout for Power X…(PW-X)

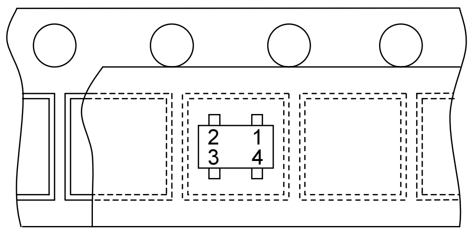




3.3.16 Tape Layout for Super-Mini Quad…(SMQ)

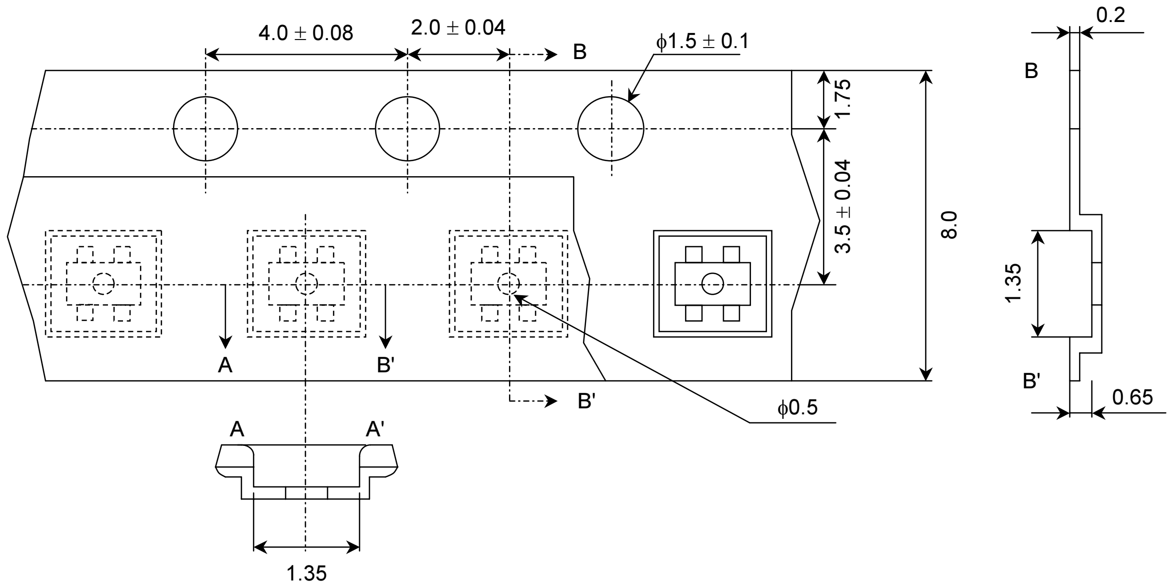


Device orientation

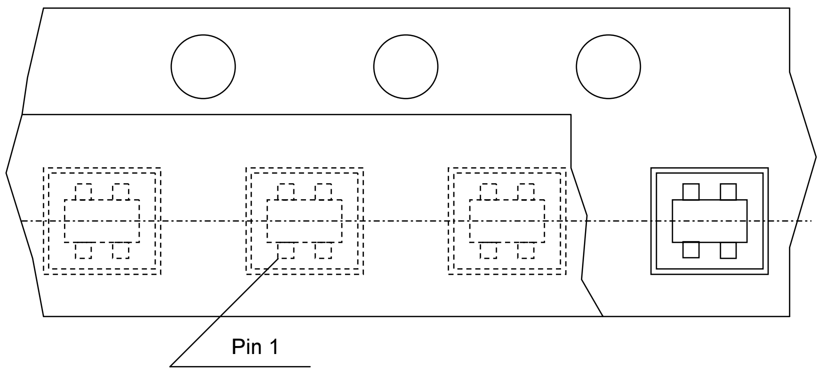


3.3.17 Tape Layout for Thin Extreme-Super-Mini Quad…(TESQ)

Unit: mm

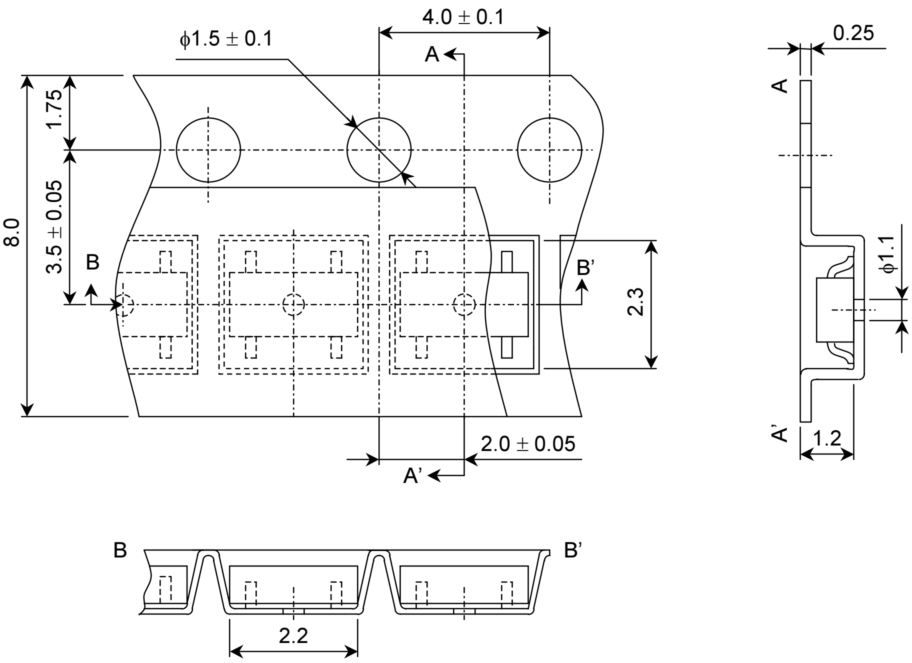


Device orientation

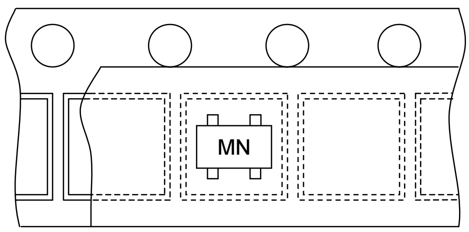


3.3.18 Tape Layout for Ultra-Super-Mini Quad…(USQ)

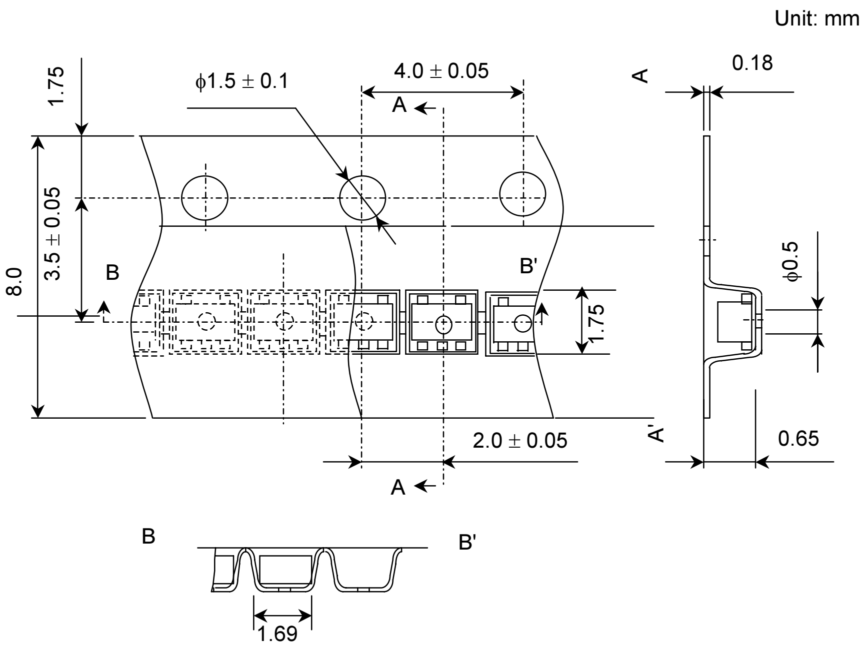
Unit: mm



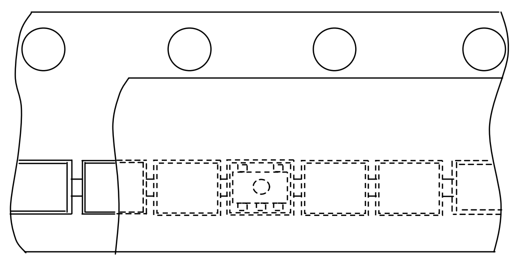
Device orientation



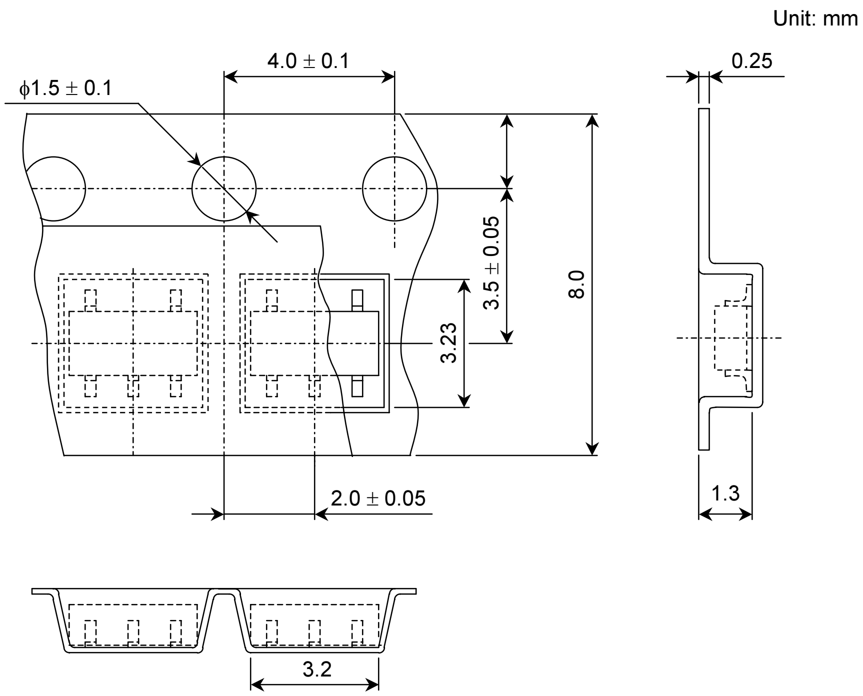
3.3.19 Tape Layout for Extreme-Super-Mini V…(ESV)



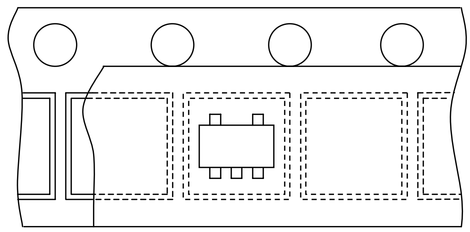
Device orientation



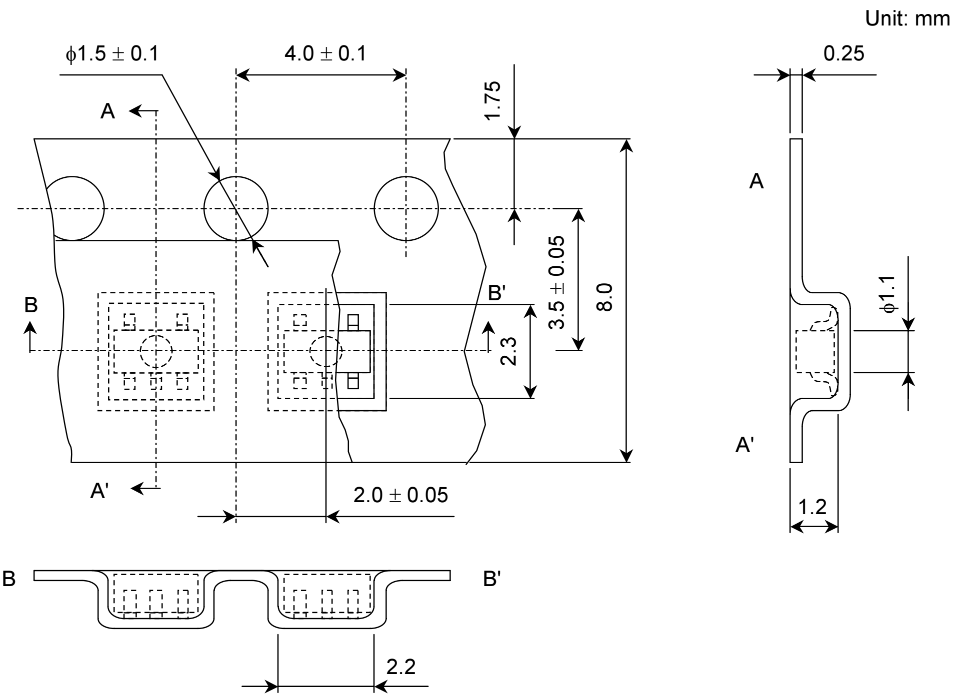
3.3.20 Tape Layout for Super-Mini V…(SMV)



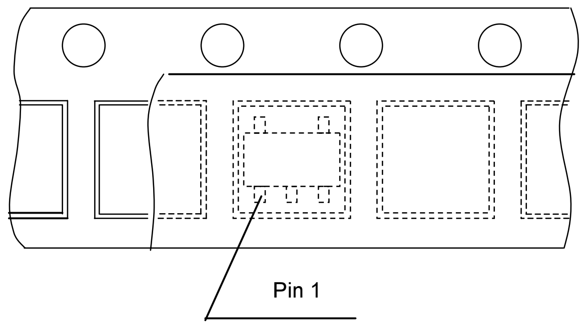
Device orientation



3.3.21 Tape Layout for Ultra-Super-Mini V…(USV)

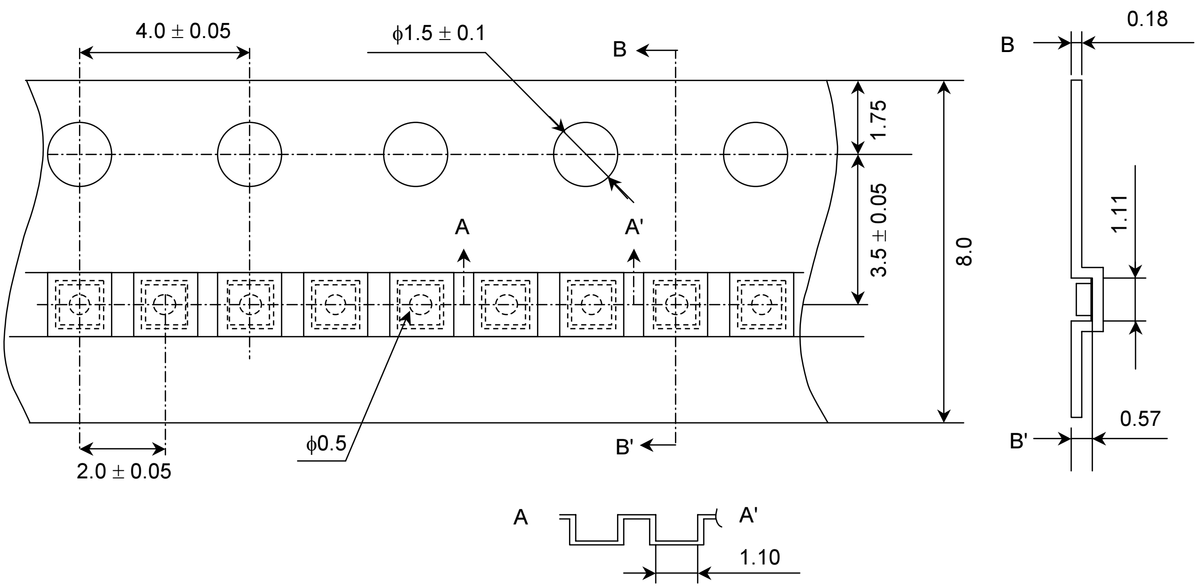


Device orientation

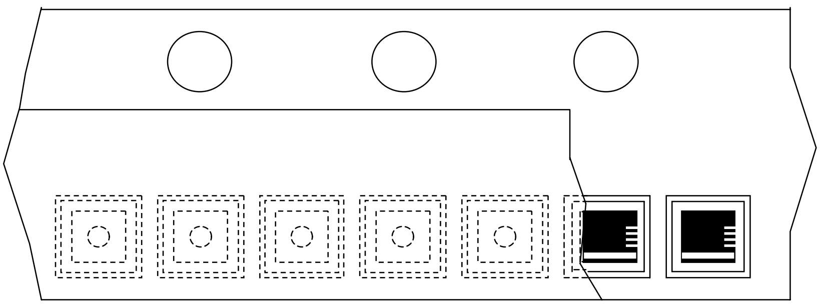


3.3.22 Tape Layout for Chip Scale 6…(CS6)

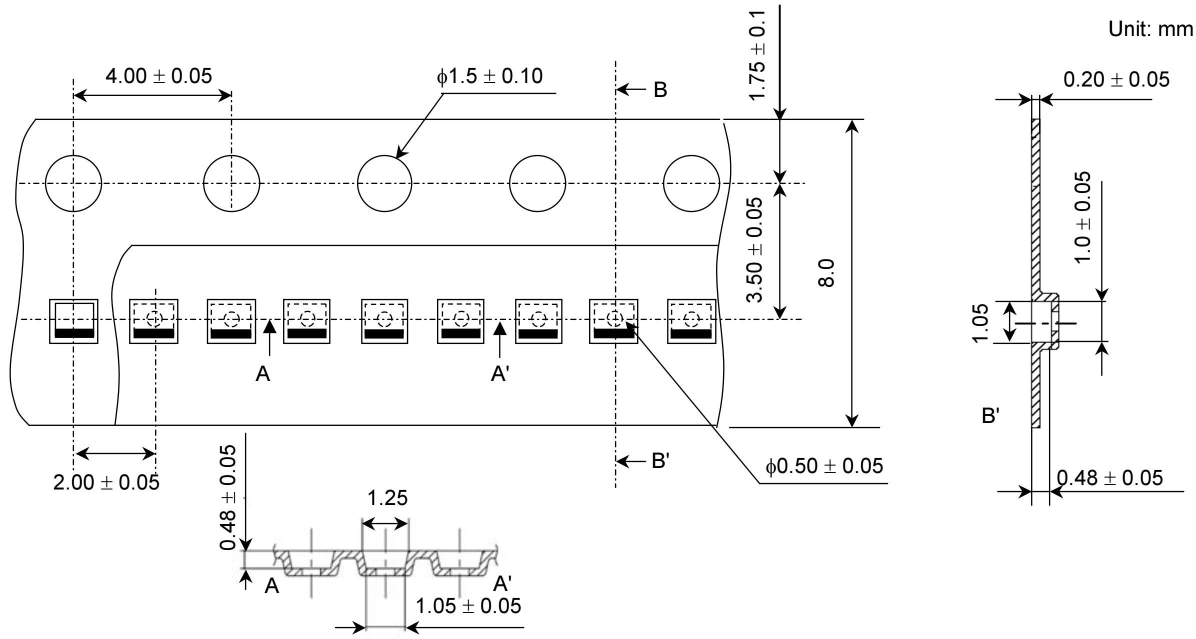
Unit: mm



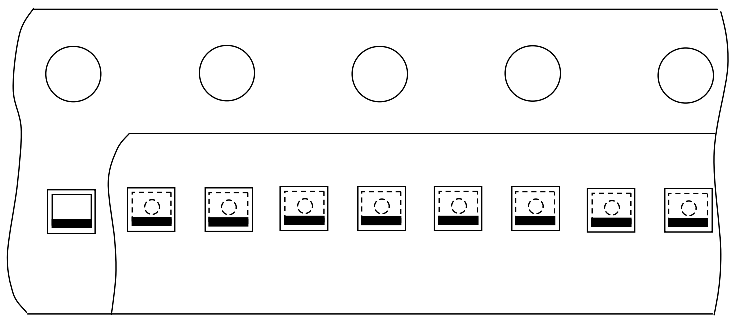
Device orientation

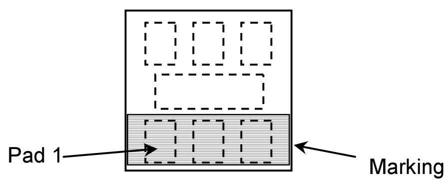


3.3.23 Tape Layout for Chip Scale Package Thin Type 6 Pin…(CST6B)

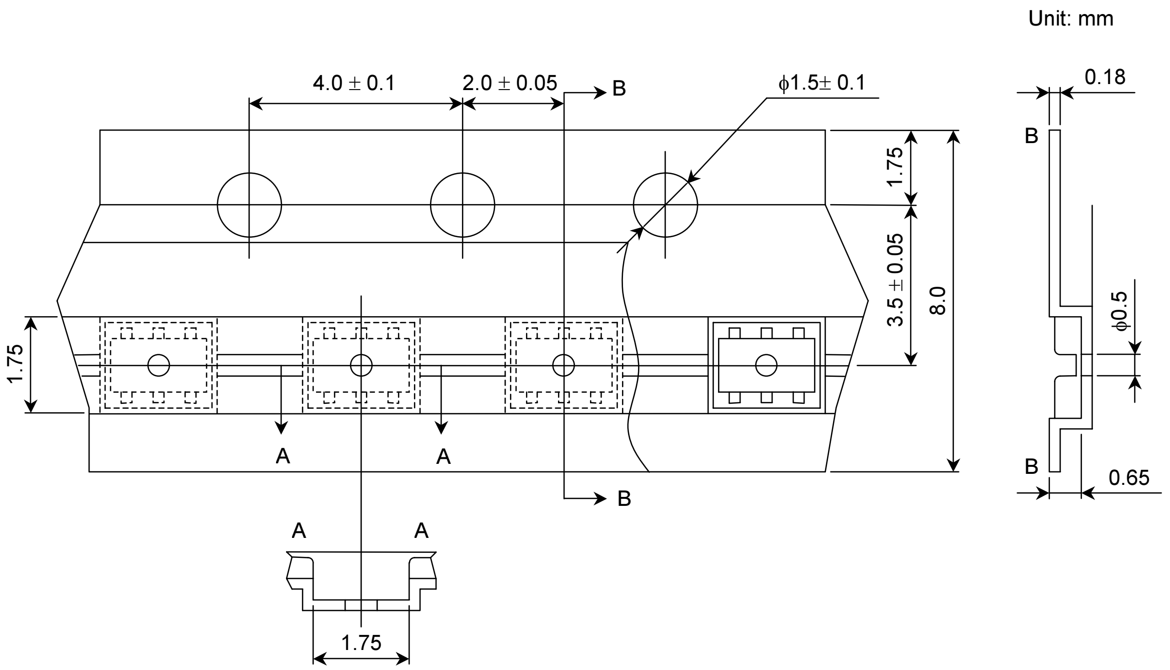


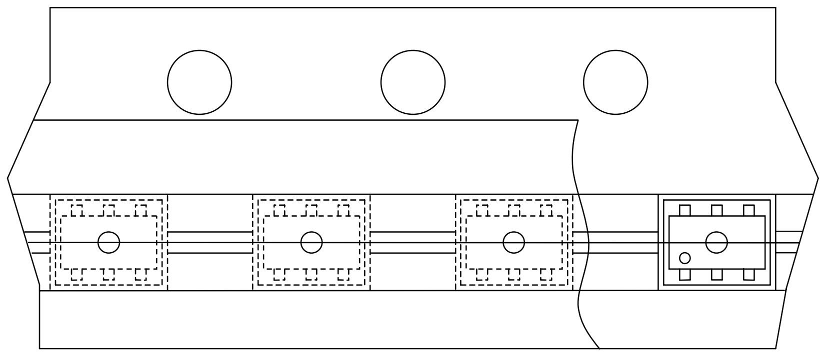
Device orientation





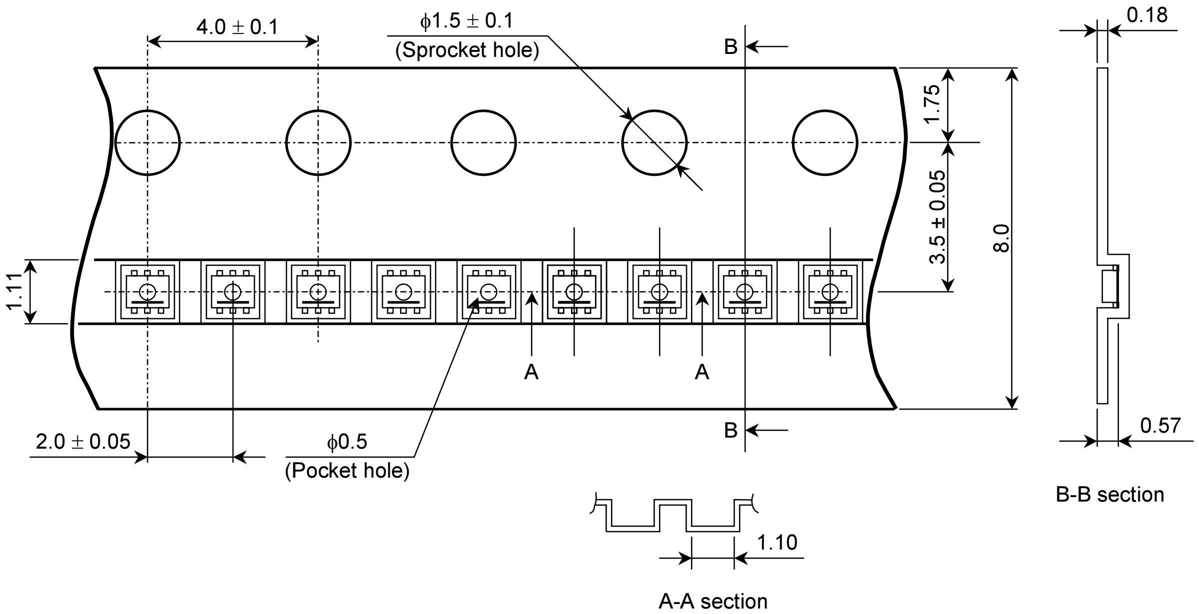
3.3.24 Tape Layout for Extreme-Super-Mini 6 Pin…(ES6)



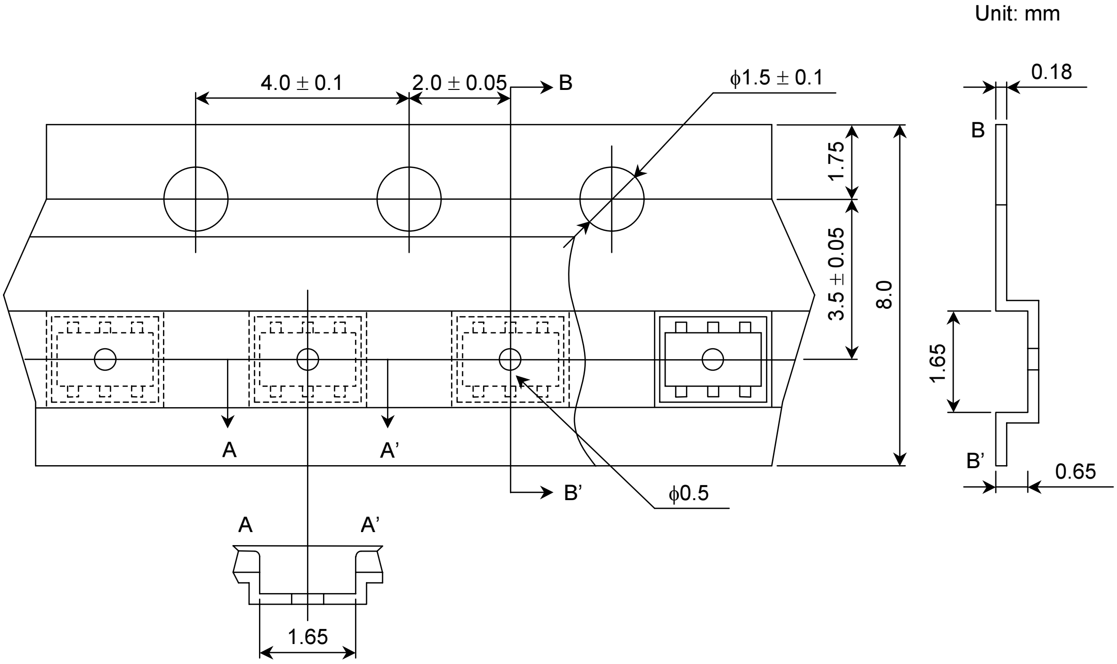


3.3.25 Tape Layout for Fine Pitch Extreme-Super-Mini 6 Pin…(fS6)

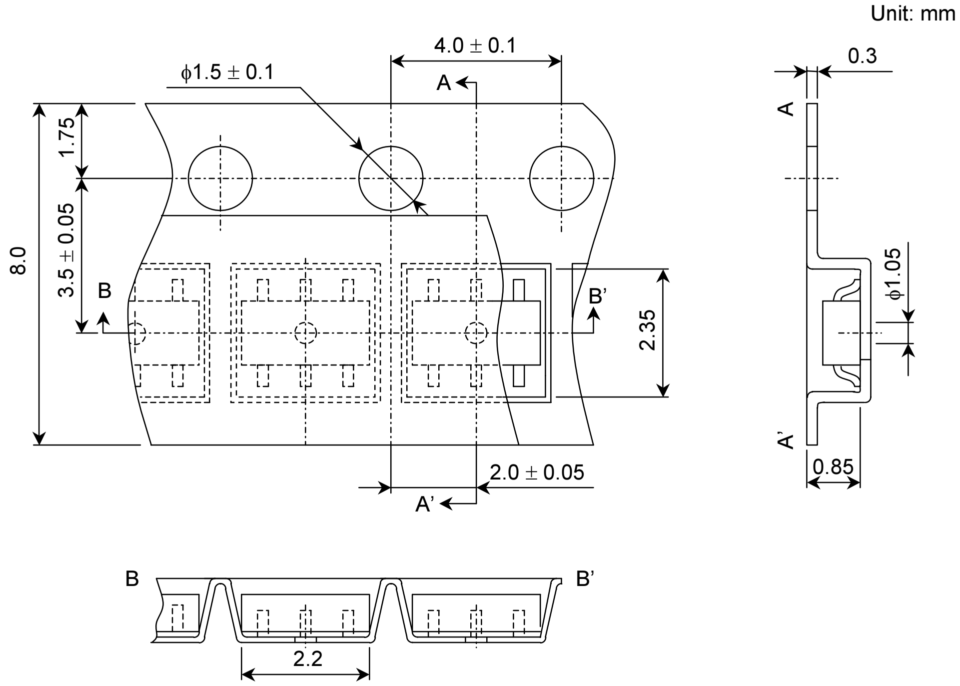
Unit: mm



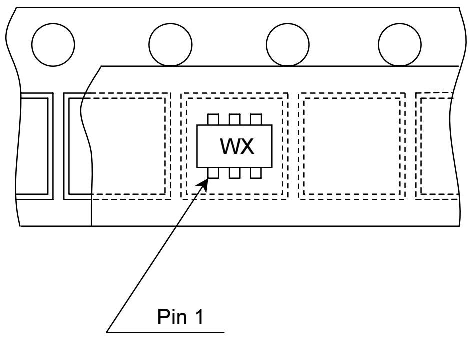
3.3.26 Tape Layout for Small Extreme-Super-Mini 6 Pin…(sES6)



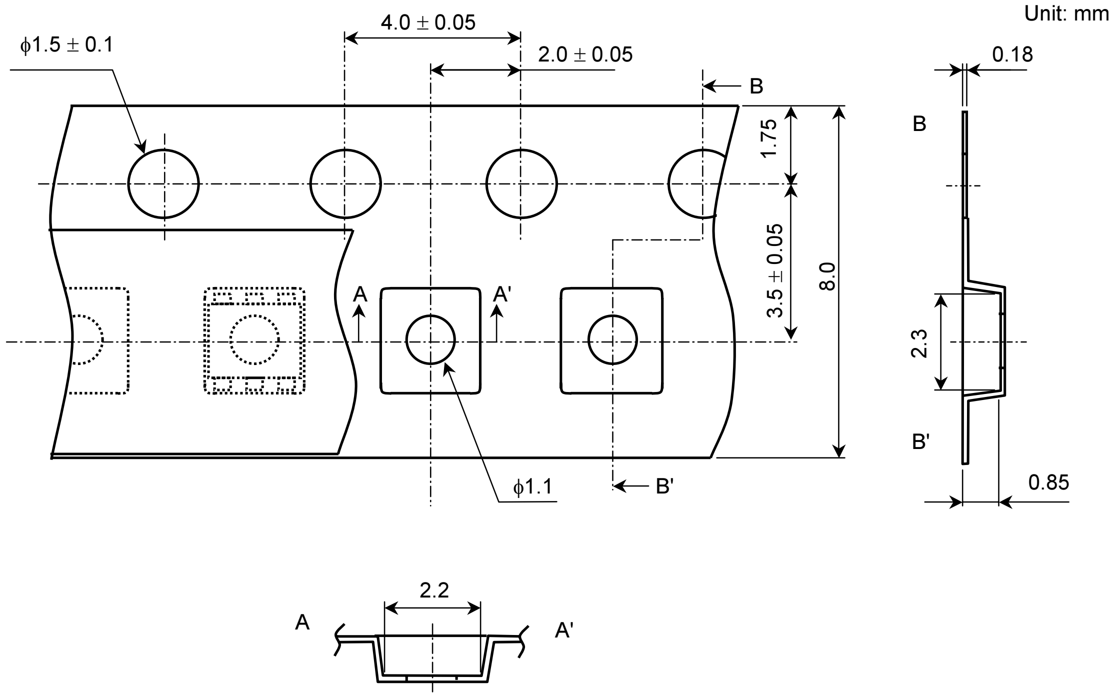
3.3.27 Tape Layout for Thin Ultra-Super-Mini 6 Pin…(TU6)



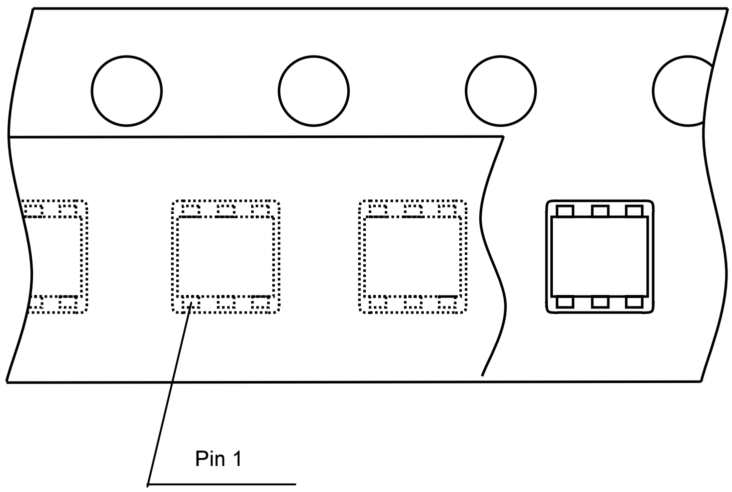
Device orientation



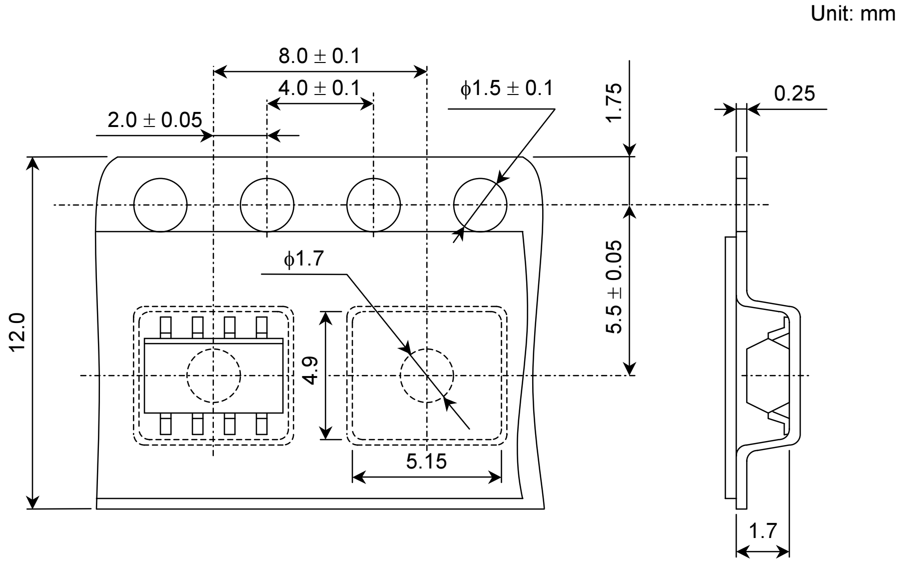
3.3.28 Tape Layout for Ultra-Flatlead 6 Pin…(UF6)

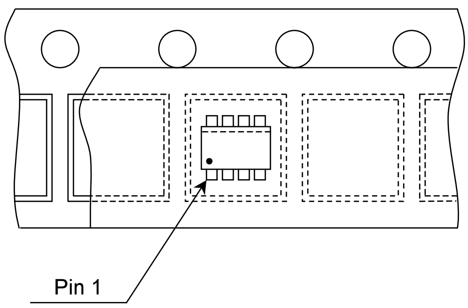


Device orientation



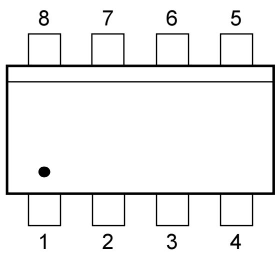
3.3.29 Tape Layout for Flat Mini 8 Pin…(FM8)



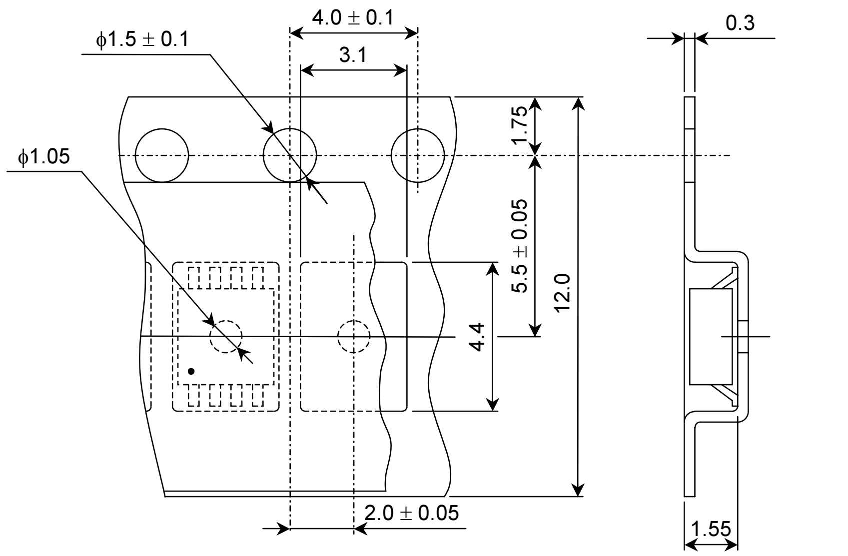


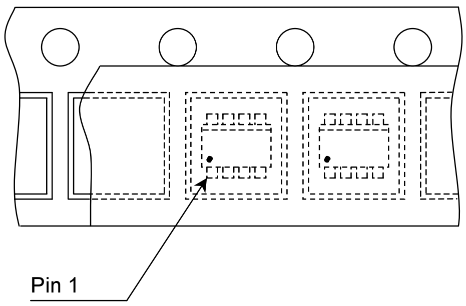
Pin 1 is on the lower left of the marking.

Example: Top View

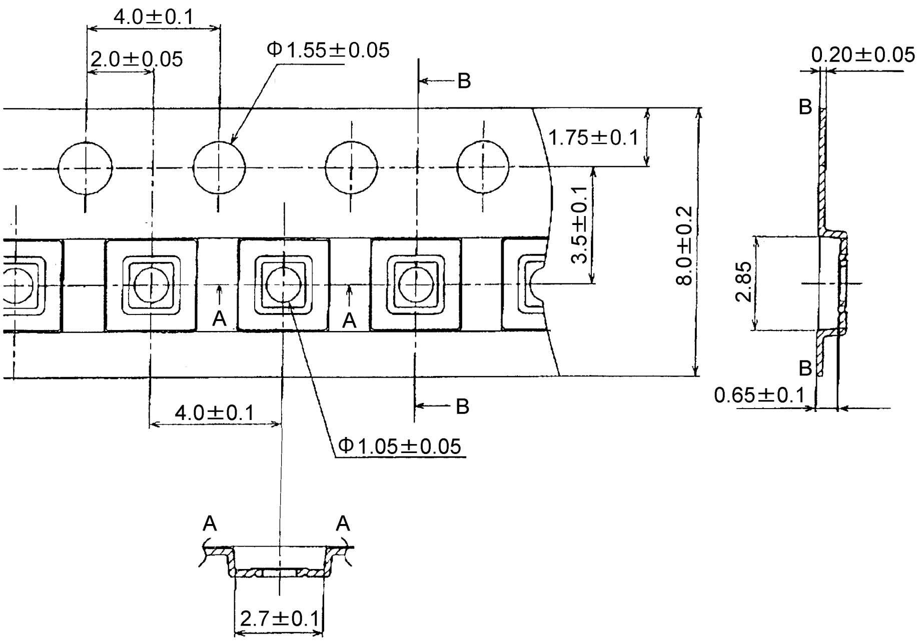


3.3.30 Tape Layout for Super-Mini 8 Pin…(SM8)

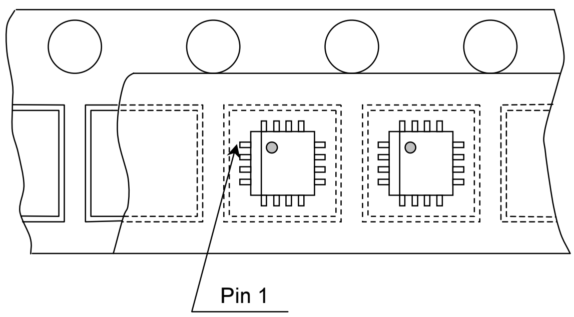




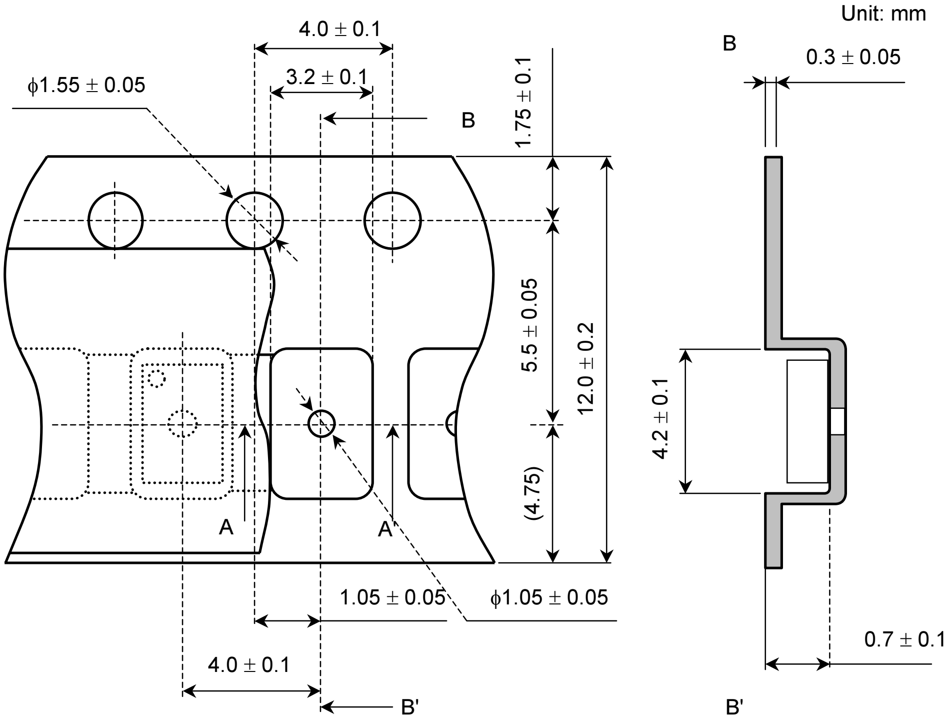
3.3.31 Tape Layout for Quad Small 16 Pin…(QS16)



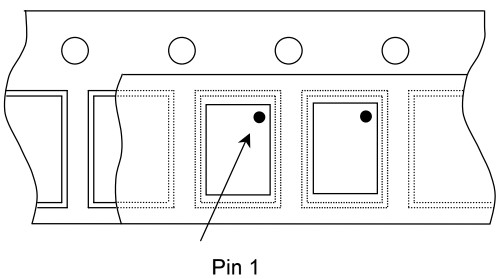
Device orientation



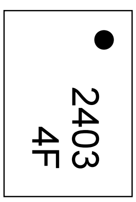
3.3.32 Tape Layout for Chip Scale Package Thin Type 20 Pin…(CST20)



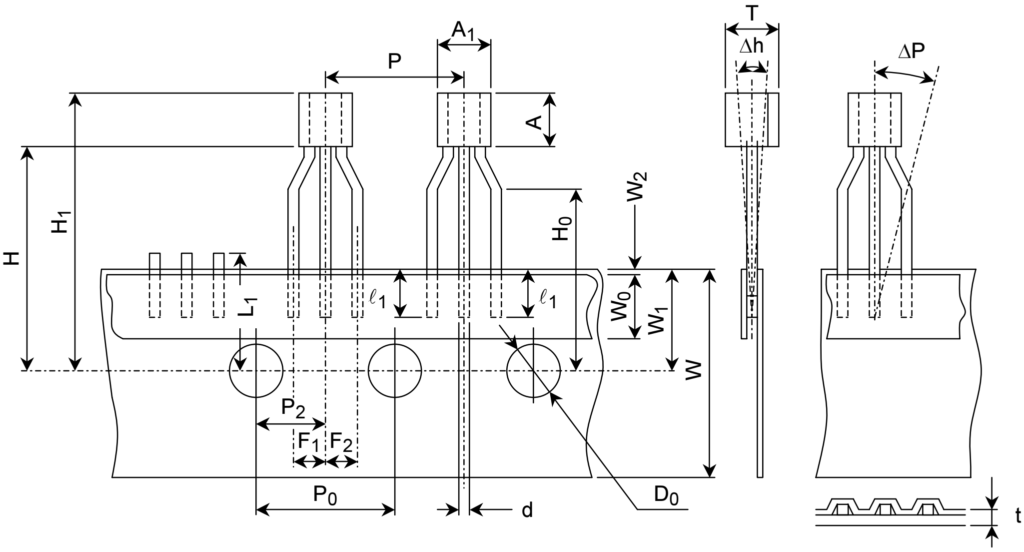
Device orientation



Example: Top View

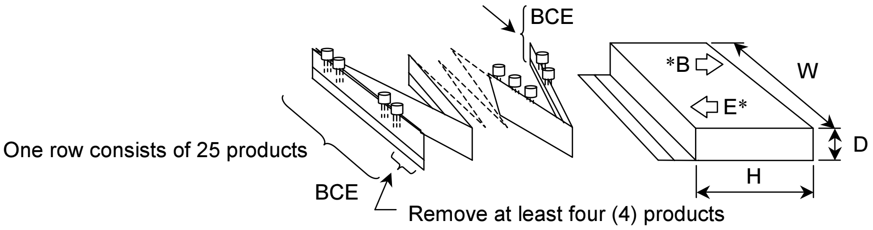


3.3.33 Radial Tape Layout for TO-92 and Mini Package



Measurement	Symbol	Dimensions			Unit: mm	Remarks
		TO-92 (SC-43)	MINI	TO-92MOD	MSTM	
Product width	A_1	6.0 max	4.5 max	5.1 max	7.1 max	Refer to each technical datasheet for more details
Product height	A	9.0 max	3.5 max	8.2 max	4.7 max	
Product thickness	T	6.0 max	2.6 max	4.1 max	2.7 max	
Lead width	d	0.45□ typ.	0.4□ typ.	0.67□ max	0.45□ typ.	
Attached lead length	ℓ_1	2.5 min		3.5 min	2.6 min	
Pitch between products	P	12.7 ± 1.0			12.7 ± 0.5	
Feed hole pitch	P_0	12.7 ± 0.3			12.7 ± 0.2	Cumulative pitch error rate: ±1 mm/20 pitches
Feed hole center to lead center	P_2	6.35 ± 0.4				
Lead spacing	F_1/F_2	$2.5^{+0.6}_{-0.3}$			$2.54^{+0.3}_{-0.2}$	
Vertical skew	Δh	0 ± 2.0			0 ± 1.0	
Tape width	W	$18.0^{+1.0}_{-0.5}$				
Sealing tape width	W_0	6.0 ± 0.3				
Tape edge to feed hole center	W_1	$9.0^{+0.75}_{-0.5}$		9.0 ± 0.5		
Carrier tape edge to sealing tape edge	W_3	0.5 max				
Package to feed hole center	H	20 max	$20^{+0.75}_{-0.5}$	20 max	19 ± 0.5	
Lead clinch to feed hole center	H_0	16.0 ± 0.5			—	
Product protrusion from feed hole center	H_1	32.25 max			25.0 max	
Feed hole diameter	D_0	4.0 ± 0.2				
Tape thickness	t	0.6 ± 0.2				
Length of shipped lead	L_1	11.0 max				
Horizontal skew	ΔP	0 ± 1.0				

Ammo Pack and Ammo Pack Dimensions



Unit: mm

Package Type	W	H	D
TO-92 (SC-43)	336 ± 3	250 ± 3	47 ± 3
MINI	336 ± 3	260 ± 3	47 ± 3
TO-92MOD	336 ± 3	190 ± 3	47 ± 3
MSTM	336 ± 3	230 ± 3	47 ± 3

*: Indicates the first electrode of a lead.

Example: E: Emitter

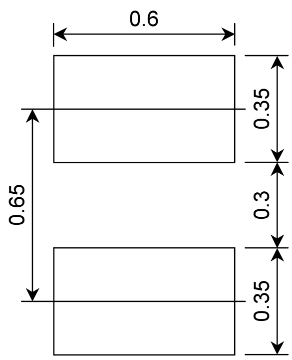
B: Base

4. Reference Pad Dimensions

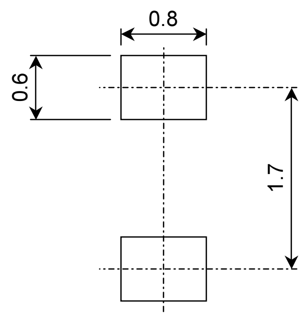
The following shows the reference pad dimensions for when a device is mounted on a board.

Unit: mm

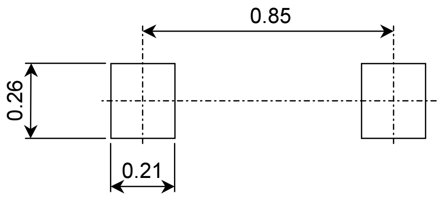
(1) CST2



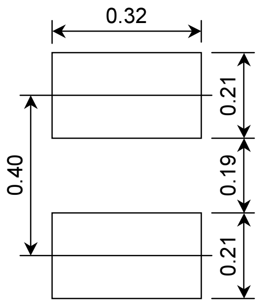
(2) ESC



(3) fSC

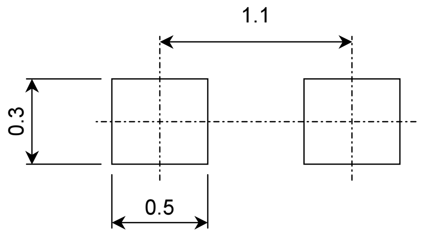


(4) SC2

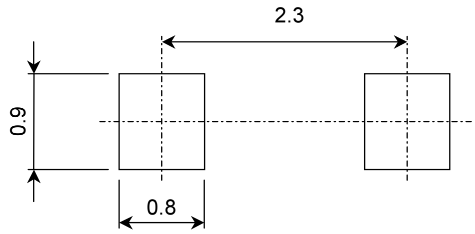


Unit: mm

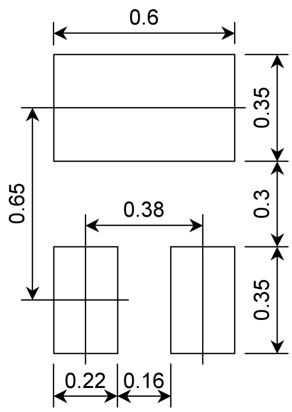
(5) sESC



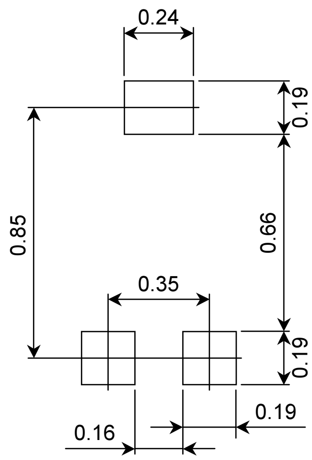
(6) USC



(7) CST3

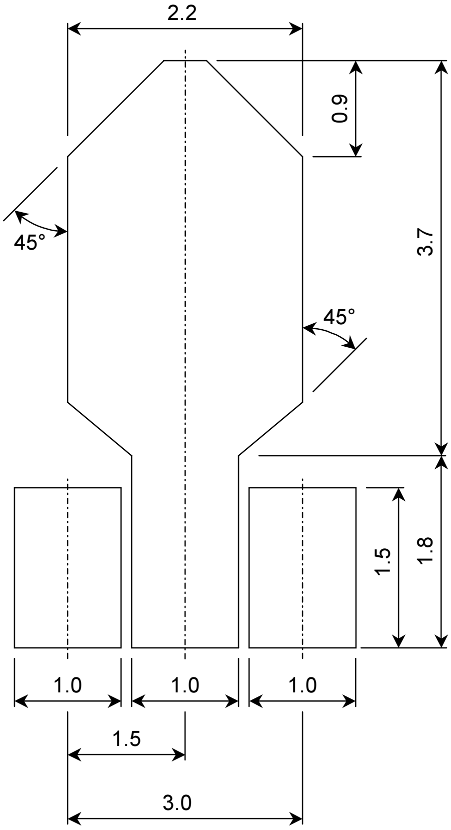


(8) fSM

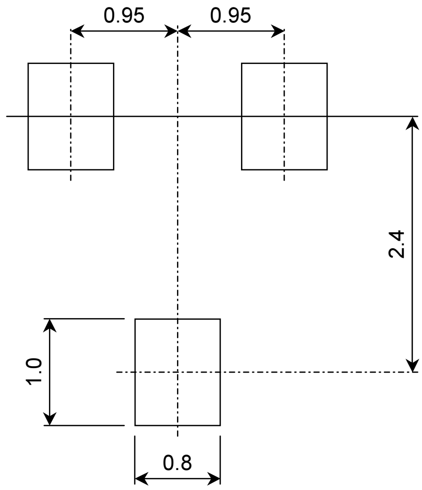


Unit: mm

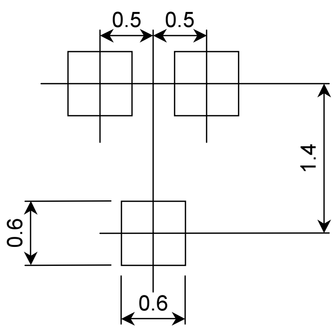
(9) PW-MINI



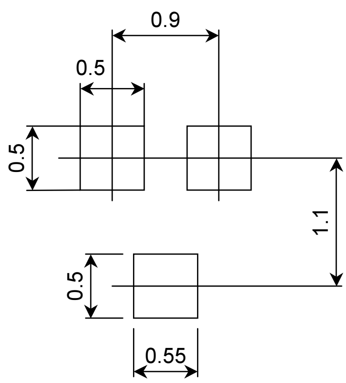
(10) S-MINI



(11) SSM

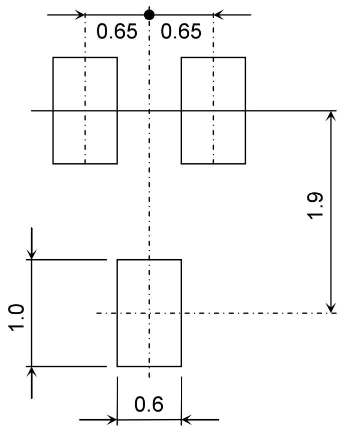


(12) TESM

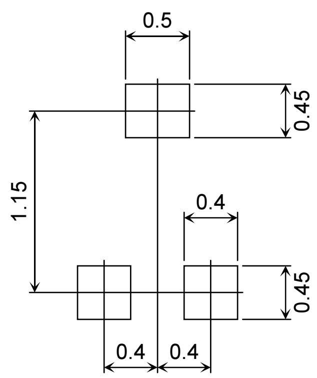


Unit: mm

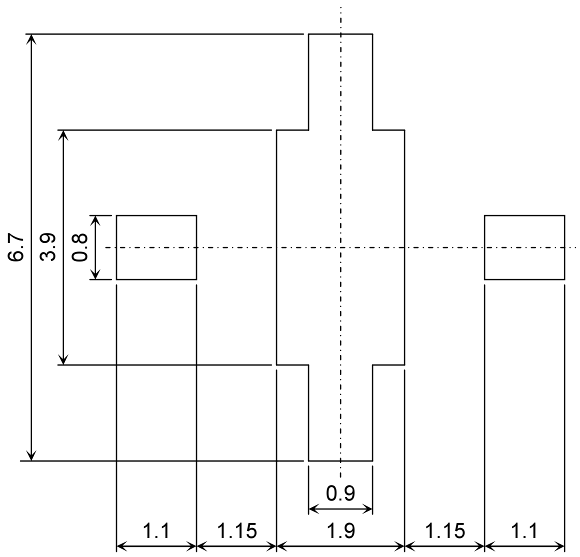
(13) USM



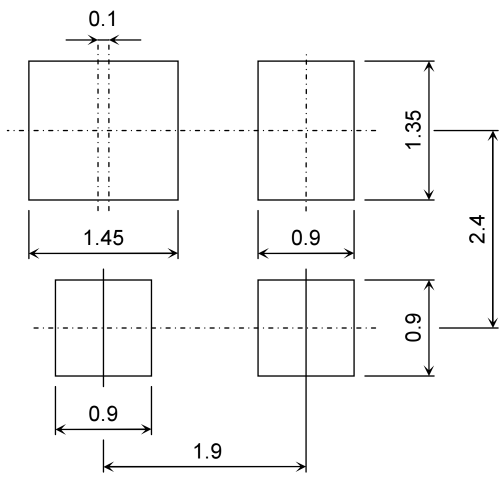
(14) VESM



(15) PW-X

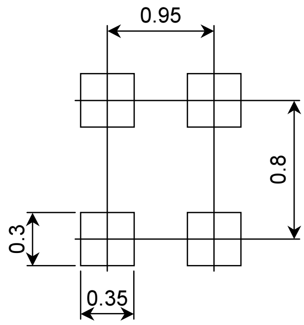


(16) SMQ

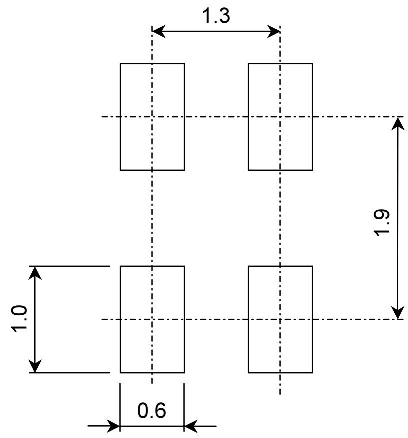


Unit: mm

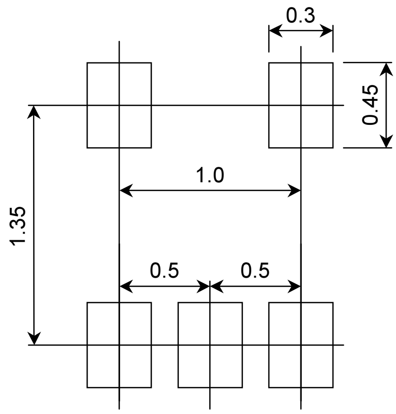
(17) TESQ



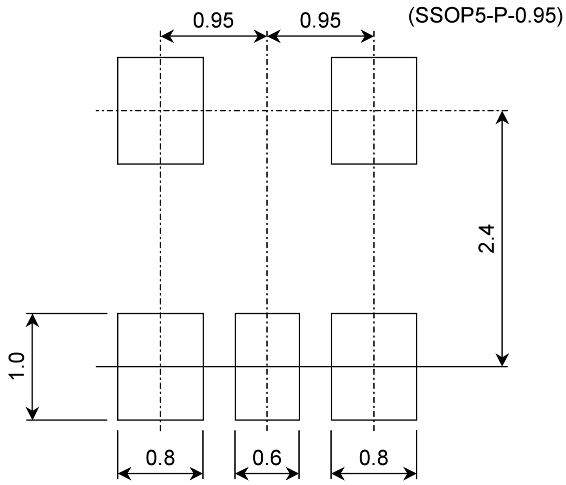
(18) USQ



(19) ESV

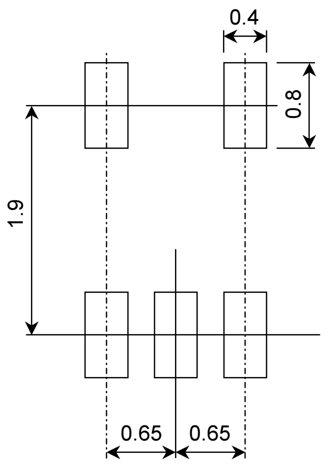


(20) SMV

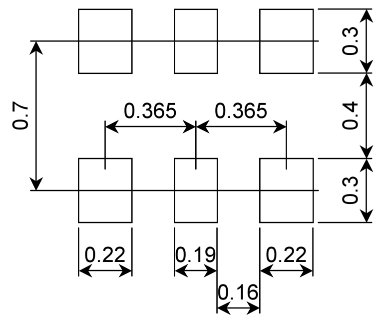


Unit: mm

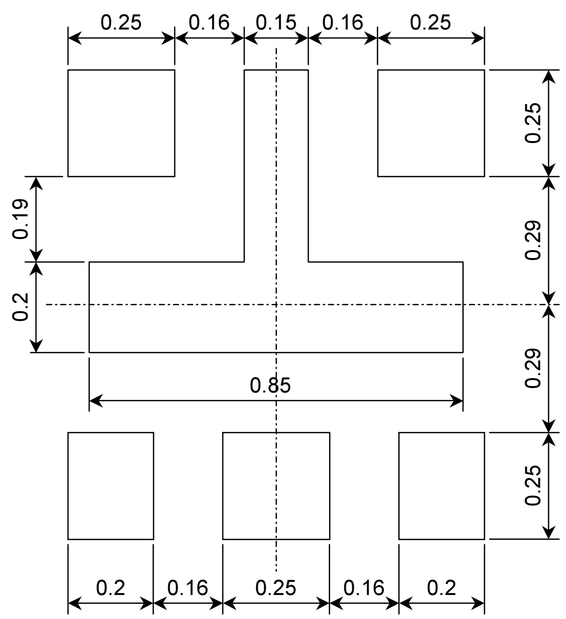
(21) USV



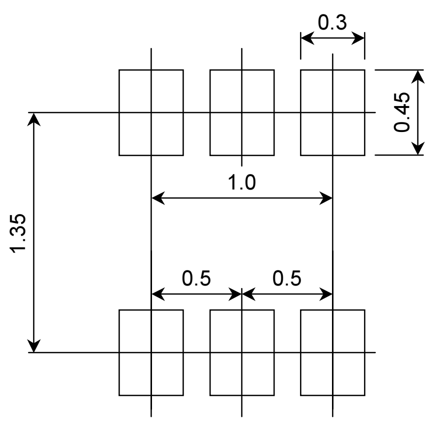
(22) CS6



(23) CST6B

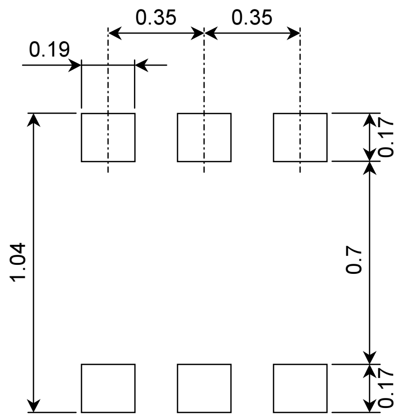


(24) ES6

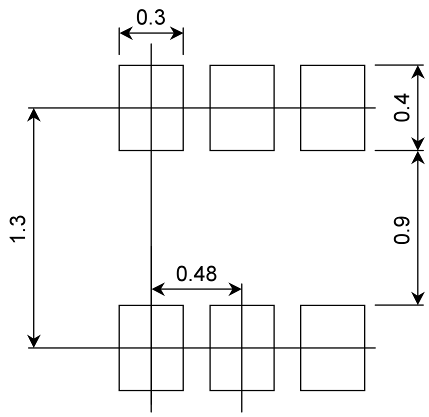


Unit: mm

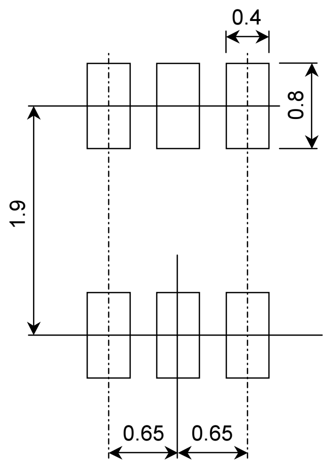
(25) fS6



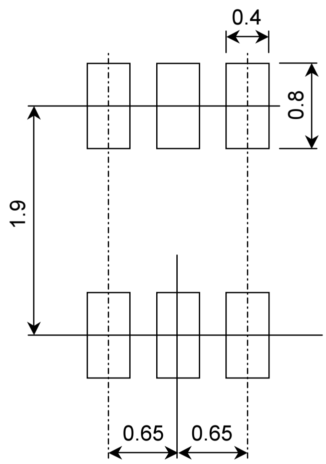
(26) sES6



(27) TU6

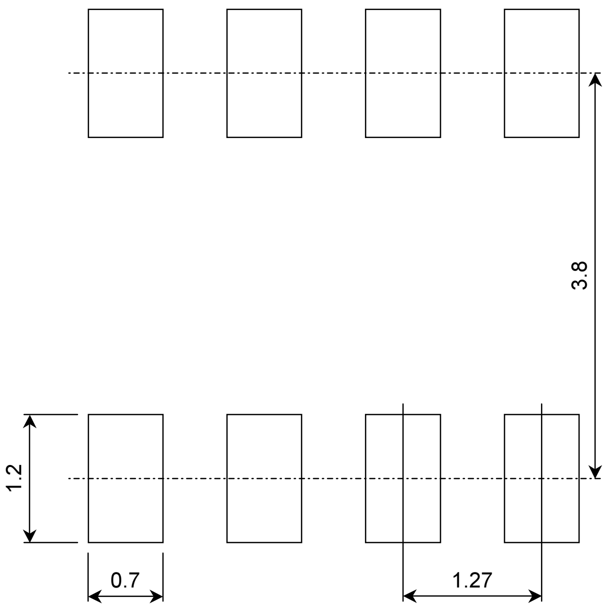


(28) UF6

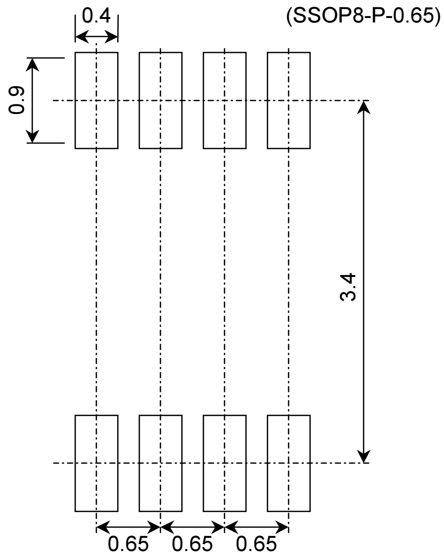


Unit: mm

(29) FM8



(30) SM8



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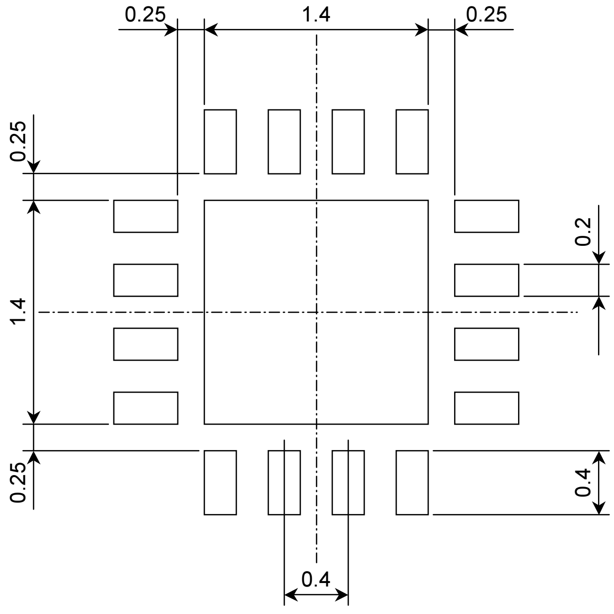
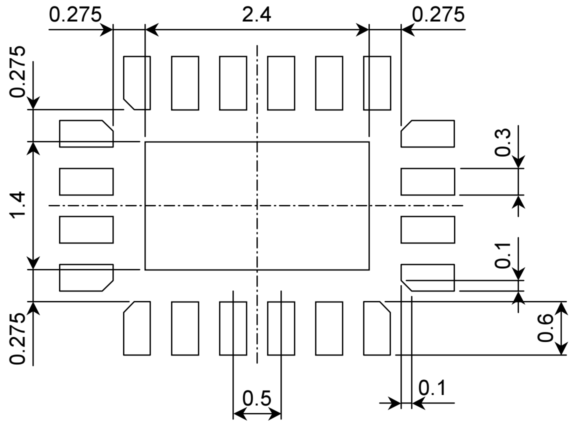


(32) CST20



[7]   Handling Precautions

[7] Handling Precautions

1. Using Toshiba Semiconductors Safely

TOSHIBA is continually working to improve the quality and reliability of its products. Nevertheless, semiconductor devices in general can malfunction or fail due to their inherent electrical sensitivity and vulnerability to physical stress. It is the responsibility of the buyer, when utilizing TOSHIBA products, to comply with the standards of safety in making a safe design for the entire system, and to avoid situations in which a malfunction or failure of such TOSHIBA products could cause loss of human life, bodily injury or damage to property.

In developing your designs, please ensure that TOSHIBA products are used within specified operating ranges as set forth in the most recent TOSHIBA products specifications. Also, please keep in mind the precautions and conditions set forth in the “Handling Guide for Semiconductor Devices,” or “TOSHIBA Semiconductor Reliability Handbook” etc..

The TOSHIBA products listed in this document are intended for usage in general electronics applications (computer, personal equipment, office equipment, measuring equipment, industrial robotics, domestic appliances, etc.). These TOSHIBA products are neither intended nor warranted for usage in equipment that requires extraordinarily high quality and/or reliability or a malfunction or failure of which may cause loss of human life or bodily injury (“Unintended Usage”). Unintended Usage include atomic energy control instruments, airplane or spaceship instruments, transportation instruments, traffic signal instruments, combustion control instruments, medical instruments, all types of safety devices, etc.. Unintended Usage of TOSHIBA products listed in this document shall be made at the customer’s own risk.

2. Safety Precautions

This section lists important precautions which users of semiconductor devices (and anyone else) should observe in order to avoid injury and damage to property, and to ensure safe and correct use of devices.

Please be sure that you understand the meanings of the labels and the graphic symbol described below before you move on to the detailed descriptions of the precautions.

[Explanation of Labels]

⚠ DANGER	Indicates an imminently hazardous situation which will result in death or serious injury if you do not follow instructions.
⚠ WARNING	Indicates a potentially hazardous situation which could result in death or serious injury if you do not follow instructions.
⚠ CAUTION	Indicates a potentially hazardous situation which if not avoided, may result in minor injury or moderate injury.

2.1 General Precautions Regarding Semiconductor Devices

CAUTION

Do not use devices under conditions exceeding their absolute maximum ratings (e.g. current, voltage, power dissipation or temperature).

This may cause the device to break down, degrade its performance, or cause it to catch fire or explode resulting in injury.

Do not insert devices in the wrong orientation.

Make sure that the positive and negative terminals of power supplies are connected correctly. Otherwise the rated maximum current or power dissipation may be exceeded and the device may break down or undergo performance degradation, causing it to catch fire or explode and resulting in injury.

When power to a device is on, do not touch the device's heat sink.

Heat sinks become hot, so you may burn your hand.

Do not touch the tips of device leads.

Because some types of device have leads with pointed tips, you may prick your finger.

When conducting any kind of evaluation, inspection or testing, be sure to connect the testing equipment's electrodes or probes to the pins of the device under test before powering it on.

Otherwise, you may receive an electric shock causing injury.

Before grounding an item of measuring equipment or a soldering iron, check that there is no electrical leakage from it.

Electrical leakage may cause the device which you are testing or soldering to break down, or could give you an electric shock.

Always wear protective glasses when cutting the leads of a device with clippers or a similar tool.

If you do not, small bits of metal flying off the cut ends may damage your eyes.

2.2 Bipolar ICs (for use in automobiles)

CAUTION

If your design includes an inductive load such as a motor coil, incorporate diodes or similar devices into the design to prevent negative current from flowing in.

The load current generated by powering the device on and off may cause it to function erratically or to break down, which could in turn cause injury.

Ensure that the power supply to any device which incorporates protective functions is stable.

If the power supply is unstable, the device may operate erratically, preventing the protective functions from working correctly. If protective functions fail, the device may break down causing injury to the user.

3. General Safety Precautions and Usage Considerations

This section is designed to help you gain a better understanding of semiconductor devices, so as to ensure the safety, quality and reliability of the devices which you incorporate into your designs.

3.1 From Incoming to Shipping

3.1.1 Electrostatic Discharge (ESD)

When handling individual devices (which are not yet mounted on a printed circuit board), be sure that the environment is protected against electrostatic electricity. Operators should wear anti-static clothing, and containers and other objects which come into direct contact with devices should be made of anti-static materials and should be grounded to earth via an 0.5- to 1.0-MΩ protective resistor.

Please follow the precautions described below; this is particularly important for devices which are marked “Be careful of static.”.

(1) Work environment

- When humidity in the working environment decreases, the human body and other insulators can easily become charged with static electricity due to friction. Maintain the recommended humidity of 40% to 60% in the work environment, while also taking into account the fact that moisture-proof-packed products may absorb moisture after unpacking.
- Be sure that all equipment, jigs and tools in the working area are grounded to earth.
- Place a conductive mat over the floor of the work area, or take other appropriate measures, so that the floor surface is protected against static electricity and is grounded to earth. The surface resistivity should be 10^4 to 10^8 Ω/sq and the resistance between surface and ground, 7.5×10^5 to 10^8 Ω
- Cover the workbench surface also with a conductive mat (with a surface resistivity of 10^4 to 10^8 Ω/sq, for a resistance between surface and ground of 7.5×10^5 to 10^8 Ω). The purpose of this is to disperse static electricity on the surface (through resistive components) and ground it to earth. Workbench surfaces must not be constructed of low-resistance metallic materials that allow rapid static discharge when a charged device touches them directly.
- Pay attention to the following points when using automatic equipment in your workplace:
  (a) When picking up ICs with a vacuum unit, use a conductive rubber fitting on the end of the pick-up wand to protect against electrostatic charge.
  (b) Minimize friction on IC package surfaces. If some rubbing is unavoidable due to the device’s mechanical structure, minimize the friction plane or use material with a small friction coefficient and low electrical resistance. Also, consider the use of an ionizer.
  (c) In sections which come into contact with device lead terminals, use a material which dissipates static electricity.
  (d) Ensure that no statically charged bodies (such as work clothes or the human body) touch the devices.

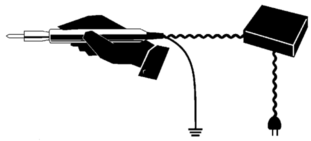
(e) Make sure that sections of the tape carrier which come into contact with installation devices or other electrical machinery are made of a low-resistance material.

(f) Make sure that jigs and tools used in the assembly process do not touch devices.

(g) In processes in which packages may retain an electrostatic charge, use an ionizer to neutralize the ions.

- Make sure that CRT displays in the working area are protected against static charge, for example by a VDT filter. As much as possible, avoid turning displays on and off. Doing so can cause electrostatic induction in devices.
- Keep track of charged potential in the working area by taking periodic measurements.
- Ensure that work chairs are protected by an anti-static textile cover and are grounded to the floor surface by a grounding chain. (suggested resistance between the seat surface and grounding chain is 7.5×10^5 to 10^{12} Ω.)
- Install anti-static mats on storage shelf surfaces. (suggested surface resistivity is 10^4 to 10^8 Ω/sq; suggested resistance between surface and ground is 7.5×10^5 to 10^8 Ω.)
- For transport and temporary storage of devices, use containers (boxes, jigs or bags) that are made of anti-static materials or materials which dissipate electrostatic charge.
- Make sure that cart surfaces which come into contact with device packaging are made of materials which will conduct static electricity, and verify that they are grounded to the floor surface via a grounding chain.
- In any location where the level of static electricity is to be closely controlled, the ground resistance level should be Class 3 or above. Use different ground wires for all items of equipment which may come into physical contact with devices.

(2) Operating environment

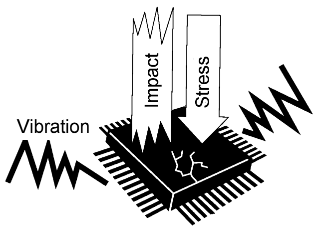


- Operators must wear anti-static clothing and conductive shoes (or a leg or heel strap).
- Operators must wear a wrist strap grounded to earth via a resistor of about 1 MΩ.
- Soldering irons must be grounded from iron tip to earth, and must be used only at low voltages (6 V to 24 V).
- If the tweezers you use are likely to touch the device terminals, use anti-static tweezers and in particular avoid metallic tweezers. If a charged device touches a low-resistance tool, rapid discharge can occur. When using vacuum tweezers, attach a conductive chucking pat to the tip, and connect it to a dedicated ground used especially for anti-static purposes (suggested resistance value: 10^4 to 10^8 Ω).
- Do not place devices or their containers near sources of strong electrical fields (such as above a CRT).
- When storing printed circuit boards which have devices mounted on them, use a board container or bag that is protected against static charge. To avoid the occurrence of static charge or discharge due to friction, keep the boards separate from one other and do not stack them directly on top of one another.
- Ensure, if possible, that any articles (such as clipboards) which are brought to any location where the level of static electricity must be closely controlled are constructed of anti-static materials.

- In cases where the human body comes into direct contact with a device, be sure to wear anti-static finger covers or gloves (suggested resistance value: $10^8\ \Omega$ or less).
- Equipment safety covers installed near devices should have resistance ratings of $10^9\ \Omega$ or less.
- If a wrist strap cannot be used for some reason, and there is a possibility of imparting friction to devices, use an ionizer.
- The transport film used in TCP products is manufactured from materials in which static charges tend to build up. When using these products, install an ionizer to prevent the film from being charged with static electricity. Also, ensure that no static electricity will be applied to the product's copper foils by taking measures to prevent static occurring in the peripheral equipment.

3.1.2 Vibration, Impact and Stress

Handle devices and packaging materials with care. To avoid damage to devices, do not toss or drop packages. Ensure that devices are not subjected to mechanical vibration or shock during transportation. Ceramic package devices and devices in canister-type packages which have empty space inside them are subject to damage from vibration and shock because the bonding wires are secured only at their ends.



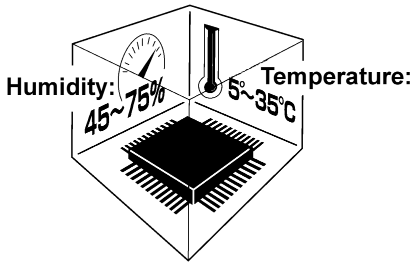
Plastic molded devices, on the other hand, have a relatively high level of resistance to vibration and mechanical shock because their bonding wires are enveloped and fixed in resin. However, when any device or package type is installed in target equipment, it is to some extent susceptible to wiring disconnections and other damage from vibration, shock and stressed solder junctions. Therefore when devices are incorporated into the design of equipment which will be subject to vibration, the structural design of the equipment must be thought out carefully.

If a device is subjected to especially strong vibration, mechanical shock or stress, the package or the chip itself may crack. In products such as CCDs which incorporate window glass, this could cause surface flaws in the glass or cause the connection between the glass and the ceramic to separate.

Furthermore, it is known that stress applied to a semiconductor device through the package changes the resistance characteristics of the chip because of piezoelectric effects. In analog circuit design attention must be paid to the problem of package stress as well as to the dangers of vibration and shock as described above.

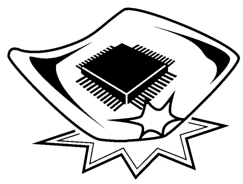
3.2 Storage

3.2.1 General Storage



- Avoid storage locations where devices will be exposed to moisture or direct sunlight.
- Follow the instructions printed on the device cartons regarding transportation and storage.
- The storage area temperature should be kept within a temperature range of 5°C to 35°C, and relative humidity should be maintained at between 45% and 75%.
- Do not store devices in the presence of harmful (especially corrosive) gases, or in dusty conditions.
- Use storage areas where there is minimal temperature fluctuation. Rapid temperature changes can cause moisture to form on stored devices, resulting in lead oxidation or corrosion. As a result, the solderability of the leads will be degraded.
- When repacking devices, use anti-static containers.
- Do not allow external forces or loads to be applied to devices while they are in storage.
- If devices have been stored for more than two years, their electrical characteristics should be tested and their leads should be tested for ease of soldering before they are used.

3.2.2 Moisture-Proof Packing



Moisture-proof packing should be handled with care. The handling procedure specified for each packing type should be followed scrupulously. If the proper procedures are not followed, the quality and reliability of devices may be degraded. This section describes general precautions for handling moisture-proof packing. Since the details may differ from device to device, refer also to the relevant individual datasheets or databook.

(1) General precautions

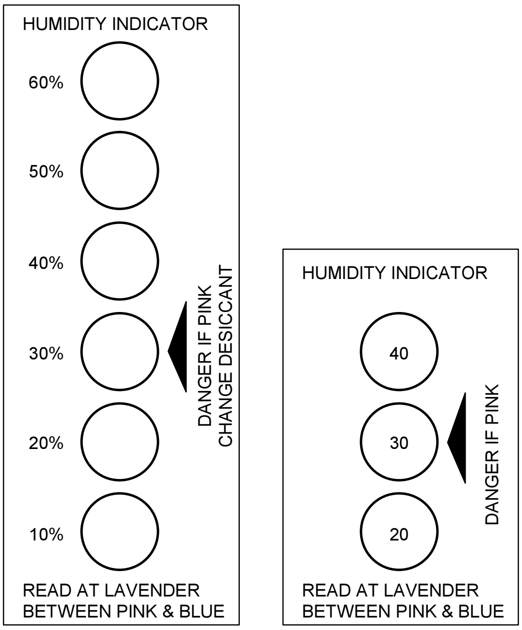
Follow the instructions printed on the device cartons regarding transportation and storage.

- Do not drop or toss device packing. The laminated aluminum material in it can be rendered ineffective by rough handling.
- The storage area temperature should be kept within a temperature range of 5°C to 30°C, and relative humidity should be maintained at 90% (max). Use devices within 12 months of the date marked on the package seal.

- If the 12-month storage period has expired, or if the 30% humidity indicator shown in Figure 3.1 is pink when the packing is opened, it may be advisable, depending on the device and packing type, to back the devices at high temperature to remove any moisture. Please refer to the table below. After the pack has been opened, use the devices in a 5°C to 30°C. 60% RH environment and within the effective usage period listed on the moisture-proof package. If the effective usage period has expired, or if the packing has been stored in a high-humidity environment, back the devices at high temperature.

Packing	Moisture Removal
Tray	If the packing bears the "Heatproof" marking or indicates the maximum temperature which it can withstand, bake at 125°C for 20 hours. (some devices require a different procedure.)
Tube	Transfer devices to trays bearing the "Heatproof" marking or indicating the temperature which they can withstand, or to aluminum tubes before baking at 125°C for 20 hours.
Tape	Deviced packed on tape cannot be baked and must be used within the effective usage period after unpacking, as specified on the packing.

- When baking devices, protect the devices from static electricity.
- Moisture indicators can detect the approximate humidity level at a standard temperature of 25°C. 6-point indicators and 3-point indicators are currently in use, but eventually all indicators will be 3-point indicators.



(a) 6-point indicator (b) 3-point indicator

Figure 3.1 Humidity Indicator

3.3 Design

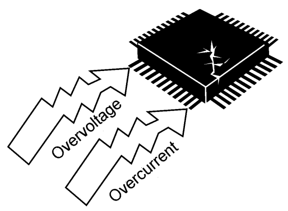
Care must be exercised in the design of electronic equipment to achieve the desired reliability. It is important not only to adhere to specifications concerning absolute maximum ratings and recommended operating conditions, it is also important to consider the overall environment in which equipment will be used, including factors such as the ambient temperature, transient noise and voltage and current surges, as well as mounting conditions which affect device reliability. This section describes some general precautions which you should observe when designing circuits and when mounting devices on printed circuit boards.

For more detailed information about each product family, refer to the relevant individual technical datasheets available from Toshiba.

3.3.1 Absolute Maximum Ratings

⚠CAUTION

Do not use devices under conditions in which their absolute maximum ratings (e.g. current, voltage, power dissipation or temperature) will be exceeded. A device may break down or its performance may be degraded, causing it to catch fire or explode resulting in injury to the user.



The absolute maximum ratings are rated values which must not be exceeded during operation, even for an instant. Although absolute maximum ratings differ from product to product, they essentially concern the voltage and current at each pin, the allowable power dissipation, and the junction and storage temperatures.

If the voltage or current on any pin exceeds the absolute maximum rating, the device's internal circuitry can become degraded. In the worst case, heat generated in internal circuitry can fuse wiring or cause the semiconductor chip to break down.

If storage or operating temperatures exceed rated values, the package seal can deteriorate or the wires can become disconnected due to the differences between the thermal expansion coefficients of the materials from which the device is constructed.

3.3.2 Recommended Operating Conditions

The recommended operating conditions for each device are those necessary to guarantee that the device will operate as specified in the datasheet.

If greater reliability is required, derate the device's absolute maximum ratings for voltage, current, power and temperature before using it.

3.3.3 Derating

When incorporating a device into your design, reduce its rated absolute maximum voltage, current, power dissipation and operating temperature in order to ensure high reliability.

Since derating differs from application to application, refer to the technical datasheets available for the various devices used in your design.

3.3.4 Unused Pins

If unused pins are left open, some devices can exhibit input instability problems, resulting in malfunctions such as abrupt increase in current flow. Similarly, if the unused output pins on a device are connected to the power supply pin, the ground pin or to other output pins, the IC may malfunction or break down.

Since the details regarding the handling of unused pins differ from device to device and from pin to pin, please follow the instructions given in the relevant individual datasheets or databook.

CMOS logic IC inputs, for example, have extremely high impedance. If an input pin is left open, it can easily pick up extraneous noise and become unstable. In this case, if the input voltage level reaches an intermediate level, it is possible that both the P-channel and N-channel transistors will be turned on, allowing unwanted supply current to flow. Therefore, ensure that the unused input pins of a device are connected to the power supply (V_{CC}) pin or ground (GND) pin of the same device. For details of what to do with the pins of heat sinks, refer to the relevant technical datasheet and databook.

3.3.5 Latch-Up

Latch-up is an abnormal condition inherent in CMOS devices, in which V_{CC} gets shorted to ground. This happens when a parasitic PN-PN junction (thyristor structure) internal to the CMOS chip is turned on, causing a large current of the order of several hundred mA or more to flow between V_{CC} and GND, eventually causing the device to break down.

Latch-up occurs when the input or output voltage exceeds the rated value, causing a large current to flow in the internal chip, or when the voltage on the V_{CC} (V_{DD}) pin exceeds its rated value, forcing the internal chip into a breakdown condition. Once the chip falls into the latch-up state, even though the excess voltage may have been applied only for an instant, the large current continues to flow between V_{CC} (V_{DD}) and GND (V_{SS}). This causes the device to heat up and, in extreme cases, to emit gas fumes as well. To avoid this problem, observe the following precautions:

(1) Do not allow voltage levels on the input and output pins either to rise above V_{CC} (V_{DD}) or to fall below GND (V_{SS}). Also, follow any prescribed power-on sequence, so that power is applied gradually or in steps rather than abruptly.

(2) Do not allow any abnormal noise signals to be applied to the device.

(3) Set the voltage levels of unused input pins to V_{CC} (V_{DD}) or GND (V_{SS}).

(4) Do not connect output pins to one another.

3.3.6 Input/Output Protection

Wired-AND configurations, in which outputs are connected together, cannot be used, since this short-circuits the outputs. Outputs should, of course, never be connected to V_{CC} (V_{DD}) or GND (V_{SS}).

Furthermore, ICs with tri-state outputs can undergo performance degradation if a shorted output current is allowed to flow for an extended period of time. Therefore, when designing circuits, make sure that tri-state outputs will not be enabled simultaneously.

3.3.7 Load Capacitance

Some devices display increased delay times if the load capacitance is large. Also, large charging and discharging currents will flow in the device, causing noise. Furthermore, since outputs are shorted for a relatively long time, wiring can become fused.

Consult the technical information for the device being used to determine the recommended load capacitance.

3.3.8 Thermal Design

The failure rate of semiconductor devices is greatly increased as operating temperatures increase. As shown in, Figure 3.2 the internal thermal stress on a device is the sum of the ambient temperature and the temperature rise due to power dissipation in the device. Therefore, to achieve optimum reliability, observe the following precautions concerning thermal design:

(1) Keep the ambient temperature (Ta) as low as possible.

(2) If the device's dynamic power dissipation is relatively large, select the most appropriate circuit board material, and consider the use of heat sinks or of forced air cooling. Such measures will help lower the thermal resistance of the package.

(3) Derate the device's absolute maximum ratings to minimize thermal stress from power dissipation.

$\theta ja = \theta jc + \theta ca$

$\theta ja = (Tj - Ta)/P$

$\theta jc = (Tj - Tc)/P$

$\theta ca = (Tc - Ta)/P$

in which θja = thermal resistance between junction and surrounding air (°C/W)

θjc = thermal resistance between junction and package surface, or internal thermal resistance (°C/W)

θca = thermal resistance between package surface and surrounding air, or external thermal resistance (°C/W)

Tj = junction temperature or chip temperature (°C)

Tc = package surface temperature or case temperature (°C)

Ta = ambient temperature (°C)

P = power dissipation (W)

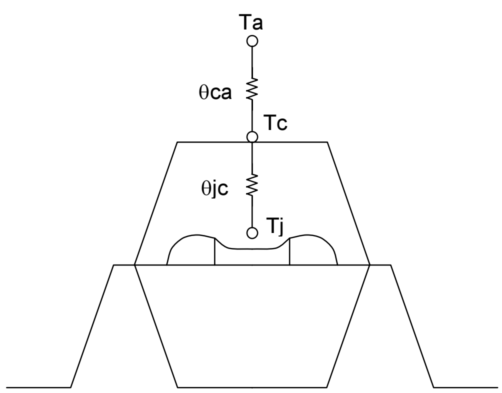


Figure 3.2 Thermal Resistance of Package

3.3.9 Interfacing

When connecting inputs and outputs between devices, make sure input voltage (V_{IL}/V_{IH}) and output voltage (V_{OL}/V_{OH}) levels are matched. Otherwise, the devices may malfunction. When connecting devices operating at different supply voltages, such as in a dual-power-supply system, be aware that erroneous power-on and power-off sequences can result in device breakdown. For details of how to interface particular devices, consult the relevant technical datasheets and databooks. If you have any questions or doubts about interfacing, contact your nearest Toshiba office or distributor.

3.3.10 Decoupling

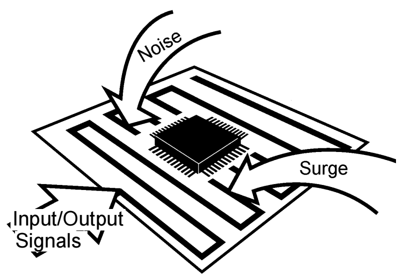
Spike currents generated during switching can cause V_{CC} (V_{DD}) and GND (V_{SS}) voltage levels to fluctuate, causing ringing in the output waveform or a delay in response speed. (the power supply and GND wiring impedance is normally 50 Ω to 100 Ω.) For this reason, the impedance of power supply lines with respect to high frequencies must be kept low. This can be accomplished by using thick and short wiring for the V_{CC} (V_{DD}) and GND (V_{SS}) lines and by installing decoupling capacitors (of approximately 0.01 μF to 1 μF capacitance) as high-frequency filters between V_{CC} (V_{DD}) and GND (V_{SS}) at strategic locations on the printed circuit board.

For low-frequency filtering, it is a good idea to install a 10- to 100-μF capacitor on the printed circuit board (one capacitor will suffice). If the capacitance is excessively large, however, (e.g. several thousand μF) latch-up can be a problem. Be sure to choose an appropriate capacitance value.

An important point about wiring is that, in the case of high-speed logic ICs, noise is caused mainly by reflection and crosstalk, or by the power supply impedance. Reflections cause increased signal delay, ringing, overshoot and undershoot, thereby reducing the device's safety margins with respect to noise. To prevent reflections, reduce the wiring length by increasing the device mounting density so as to lower the inductance (L) and capacitance (C) in the wiring. Extreme care must be taken, however, when taking this corrective measure, since it tends to cause crosstalk between the wires. In practice, there must be a trade-off between these two factors.

3.3.11 External Noise

Printed circuit boards with long I/O or signal pattern lines are vulnerable to induced noise or surges from outside sources. Consequently, malfunctions or breakdowns can result from overcurrent or overvoltage, depending on the types of device used. To protect against noise, lower the impedance of the pattern line or insert a noise-canceling circuit. Protective measures must also be taken against surges.



For details of the appropriate protective measures for a particular device, consult the relevant databook.

3.3.12 Electromagnetic Interference

Widespread use of electrical and electronic equipment in recent years has brought with it radio and TV reception problems due to electromagnetic interference. To use the radio spectrum effectively and to maintain radio communications quality, each country has formulated regulations limiting the amount of electromagnetic interference which can be generated by individual products.

Electromagnetic interference includes conduction noise propagated through power supply and telephone lines, and noise from direct electromagnetic waves radiated by equipment. Different measurement methods and corrective measures are used to assess and counteract each specific type of noise.

Difficulties in controlling electromagnetic interference derive from the fact that there is no method available which allows designers to calculate, at the design stage, the strength of the electromagnetic waves which will emanate from each component in a piece of equipment. For this reason, it is only after the prototype equipment has been completed that the designer can take measurements using a dedicated instrument to determine the strength of electromagnetic interference waves. Yet it is possible during system design to incorporate some measures for the prevention of electromagnetic interference, which can facilitate taking corrective measures once the design has been completed. These include installing shields and noise filters, and increasing the thickness of the power supply wiring patterns on the printed circuit board. One effective method, for example, is to devise several shielding options during design, and then select the most suitable shielding method based on the results of measurements taken after the prototype has been completed.

3.3.13 Peripheral Circuits

In most cases semiconductor devices are used with peripheral circuits and components. The input and output signal voltages and currents in these circuits must be chosen to match the semiconductor device’s specifications. The following factors must be taken into account.

(1) Inappropriate voltages or currents applied to a device’s input pins may cause it to operate erratically. Some devices contain pull-up or pull-down resistors. When designing your system, remember to take the effect of this on the voltage and current levels into account.

(2) The output pins on a device have a predetermined external circuit drive capability. If this drive capability is greater than that required, either incorporate a compensating circuit into your design or carefully select suitable components for use in external circuits.

3.3.14 Safety Standards

Each country has safety standards which must be observed. These safety standards include requirements for quality assurance systems and design of device insulation. Such requirements must be fully taken into account to ensure that your design conforms to the applicable safety standards.

3.3.15 Other Precautions

(1) When designing a system, be sure to incorporate fail-safe and other appropriate measures according to the intended purpose of your system. Also, be sure to debug your system under actual board-mounted conditions.

(2) If a plastic-package device is placed in a strong electric field, surface leakage may occur due to the charge-up phenomenon, resulting in device malfunction. In such cases take appropriate measures to prevent this problem, for example by protecting the package surface with a conductive shield.

(3) With some microcomputers and MOS memory devices, caution is required when powering on or resetting the device. To ensure that your design does not violate device specifications, consult the relevant databook for each constituent device.

(4) Ensure that no conductive material or object (such as a metal pin) can drop onto and short the leads of a device mounted on a printed circuit board.

3.4 Inspection, Testing and Evaluation

3.4.1 Grounding

⚠CAUTION

Ground all measuring instruments, jigs, tools and soldering irons to earth.
Electrical leakage may cause a device to break down or may result in electric shock.

3.4.2 Inspection Sequence

⚠CAUTION

1) Do not insert devices in the wrong orientation. Make sure that the positive and negative electrodes of the power supply are correctly connected. Otherwise, the rated maximum current or maximum power dissipation may be exc0eeded and the device may break down or undergo performance degradation, causing it to catch fire or explode, resulting in injury to the user.

2) When conducting any kind of evaluation, inspection or testing using AC power with a peak voltage of 42.4 V or DC power exceeding 60 V, be sure to connect the electrodes or probes of the testing equipment to the device under test before powering it on. Connecting the electrodes or probes of testing equipment to a device while it is powered on may result in electric shock, causing injury.

(1) Apply voltage to the test jig only after inserting the device securely into it. When applying or removing power, observe the relevant precautions, if any.

(2) Make sure that the voltage applied to the device is off before removing the device from the test jig. Otherwise, the device may undergo performance degradation or be destroyed.

(3) Make sure that no surge voltages from the measuring equipment are applied to the device.

(4) The chips housed in tape carrier packages (TCPs) are bare chips and are therefore exposed. During inspection take care not to crack the chip or cause any flaws in it.
Electrical contact may also cause a chip to become faulty. Therefore make sure that nothing comes into electrical contact with the chip.

3.5 Mounting

There are essentially two main types of semiconductor device package: lead insertion and surface mount. During mounting on printed circuit boards, devices can become contaminated by flux or damaged by thermal stress from the soldering process. With surface-mount devices in particular, the most significant problem is thermal stress from solder reflow, when the entire package is subjected to heat. This section describes a recommended temperature profile for each mounting method, as well as general precautions which you should take when mounting devices on printed circuit boards. Note, however, that even for devices with the same package type, the appropriate mounting method varies according to the size of the chip and the size and shape of the lead frame. Therefore, please consult the relevant technical datasheet and databook.

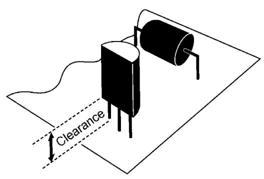
3.5.1 Lead Forming

CAUTION

1) Always wear protective glasses when cutting the leads of a device with clippers or a similar tool. If you do not, small bits of metal flying off the cut ends may damage your eyes.
2) Do not touch the tips of device leads. Because some types of device have leads with pointed tips, you oay prick your finger.

Semiconductor devices must undergo a process in which the leads are cut and formed before the devices can be mounted on a printed circuit board. If undue stress is applied to the interior of a device during this process, mechanical breakdown or performance degradation can result. This is attributable primarily to differences between the stress on the device's external leads and the stress on the internal leads. If the relative difference is great enough, the device's internal leads, adhesive properties or sealant can be damaged. Observe these precautions during the lead-forming process (this does not apply to surface-mount devices):

(1) Lead insertion hole intervals on the printed circuit board should match the lead pitch of the device precisely.
(2) If lead insertion hole intervals on the printed circuit board do not precisely match the lead pitch of the device, do not attempt to forcibly insert devices by pressing on them or by pulling on their leads.
(3) For the minimum clearance specification between a device and a printed circuit board, refer to the relevant device's datasheet and databook. If necessary, achieve the required clearance by forming the device's leads appropriately. Do not use the spacers which are used to raise devices above the surface of the printed circuit board during soldering to achieve clearance. These spacers normally continue to expand due to heat, even after the solder has begun to solidify; this applies severe stress to the device.



(4) Observe the following precautions when forming the leads of a device prior to mounting.

- Use a tool or jig to secure the lead at its base (where the lead meets the device package) while bending so as to avoid mechanical stress to the device. Also avoid bending or stretching device leads repeatedly.
- Be careful not to damage the lead during lead forming.
- Follow any other precautions described in the individual datasheets and databooks for each device and package type.

3.5.2 Mounting on Printed Circuit Board

When soldering the leads on the printed circuit board, be careful not to leave stress on the leads.

Leads must be shaped and aligned to the hole size, and space must be left between the device and the board (Figure 3.6). If leads are not shaped but forced into holes or stress is applied by a tool, corrosion or whiskers may occur where stress is applied, resulting in cutout or shorting of leads. Thus, hole size must be aligned to the lead interval.

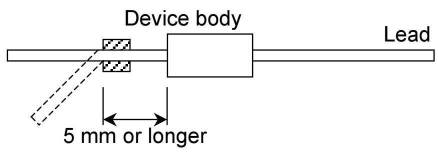


Figure 3.3 How to Bend Leads

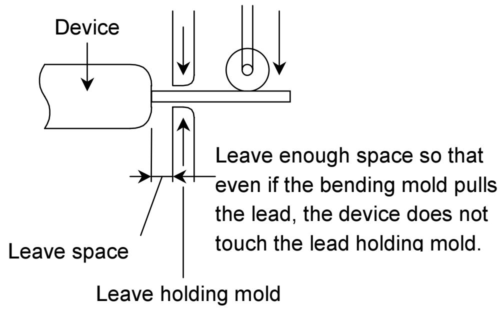


Figure 3.4 How to Bend Leads Using Metal Mold

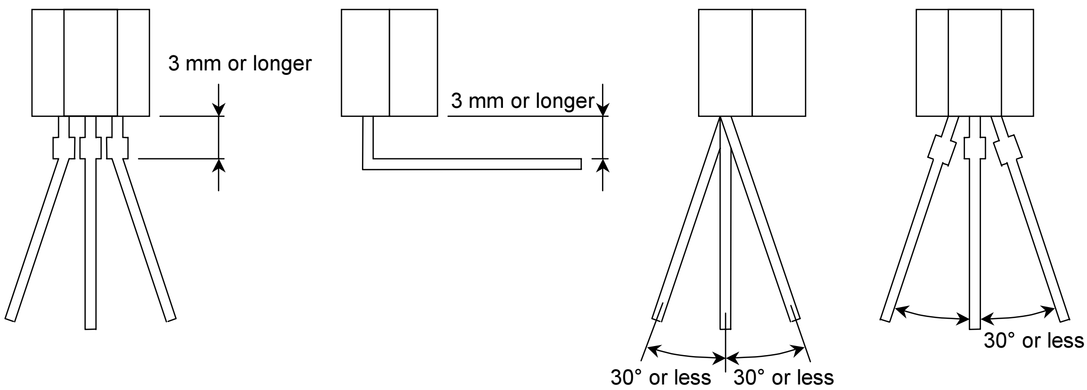


Figure 3.5 How to Bend Leads

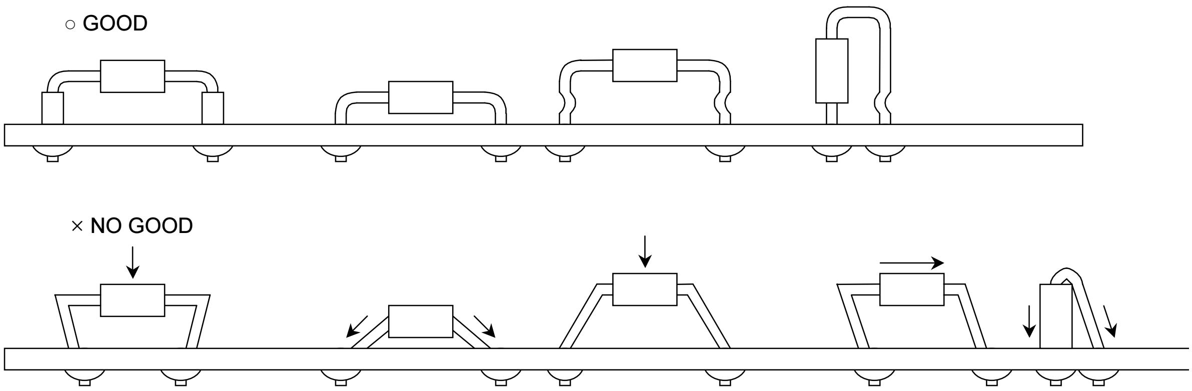


Figure 3.6 Example of Mounting on Printed-Circuit Board

3.5.3 Socket Mounting

(1) When socket mounting devices on a printed circuit board, use sockets which match the inserted device's package.

(2) Use sockets whose contacts have the appropriate contact pressure. If the contact pressure is insufficient, the socket may not make a perfect contact when the device is repeatedly inserted and removed; if the pressure is excessively high, the device leads may be bent or damaged when they are inserted into or removed from the socket.

(3) When soldering sockets to the printed circuit board, use sockets whose construction prevents flux from penetrating into the contacts or which allows flux to be completely cleaned off.

(4) Make sure the coating agent applied to the printed circuit board for moisture-proofing purposes does not stick to the socket contacts.

(5) If the device leads are severely bent by a socket as it is inserted or removed and you wish to repair the leads so as to continue using the device, make sure that this lead correction is only performed once. Do not use devices whose leads have been corrected more than once.

(6) If the printed circuit board with the devices mounted on it will be subjected to vibration from external sources, use sockets which have a strong contact pressure so as to prevent the sockets and devices from vibrating relative to one another.

3.5.4 Soldering Temperature Profile

The soldering temperature and heating time vary from device to device. Therefore, when specifying the mounting conditions, refer to the individual datasheets and databooks for the devices used.

(1) Using a soldering iron

Complete soldering within ten seconds for lead temperatures of up to 260°C, or within three seconds for lead temperatures of up to 350°C.

(2) Using medium infrared ray reflow

- Heating top and bottom with long or medium infrared rays is recommended (see Figure 3.7).

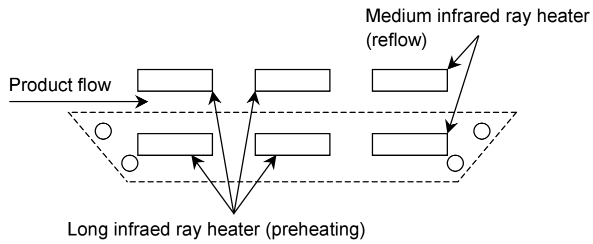


Figure 3.7 Heating Top and Bottom with Long or Medium Infrared Rays

- Complete the infrared ray reflow process within 30 seconds at a package surface temperature of between 210°C and 240°C.
- Refer to Figure 3.8 for an example of a good temperature profile for infrared or hot air reflow.

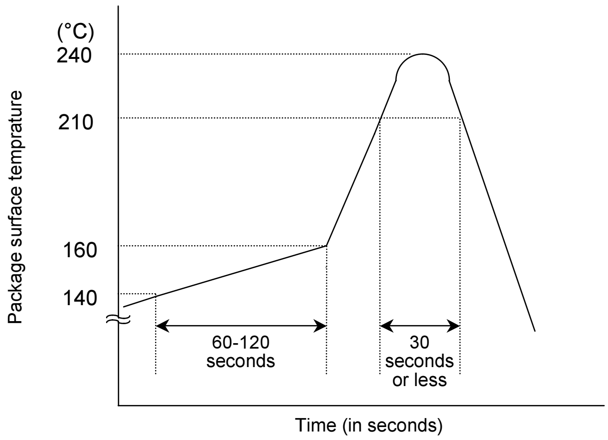


Figure 3.8 Sample Temperature Profile for Infrared or Hot Air Reflow

(3) Using hot air reflow

- Complete hot air reflow within 30 seconds at a package surface temperature of between 210°C and 240°C.
- For an example of a recommended temperature profile, refer to Figure 3.8 above.

(4) Using solder flow

- Apply preheating for 60 to 120 seconds at a temperature of 150°C.
- For lead insertion-type packages, complete solder flow within 10 seconds with the temperature at the stopper (or, if there is no stopper, at a location more than 1.5 mm from the body) which does not exceed 260°C.
- For surface-mount packages, complete soldering within 5 seconds at a temperature of 250°C or less in order to prevent thermal stress in the device.

- Figure 3.9 shows an example of a recommended temperature profile for surface-mount packages using solder flow.

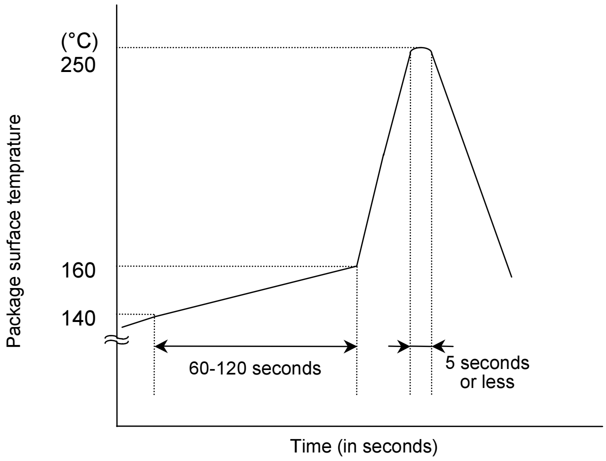


Figure 3.9 Sample Temperature Profile for Solder Flow

3.5.5 Flux Cleaning and Ultrasonic Cleaning

(1) When cleaning circuit boards to remove flux, make sure that no residual reactive ions such as Na or Cl remain. Note that organic solvents react with water to generate hydrogen chloride and other corrosive gases which can degrade device performance.

(2) Washing devices with water will not cause any problems. However, make sure that no reactive ions such as sodium and chlorine are left as a residue. Also, be sure to dry devices sufficiently after washing.

(3) Do not rub device markings with a brush or with your hand during cleaning or while the devices are still wet from the cleaning agent. Doing so can rub off the markings.

(4) The dip cleaning, shower cleaning and steam cleaning processes all involve the chemical action of a solvent. Use only recommended solvents for these cleaning methods. When immersing devices in a solvent or steam bath, make sure that the temperature of the liquid is 50°C or below, and that the circuit board is removed from the bath within one minute.

(5) Ultrasonic cleaning should not be used with hermetically-sealed ceramic packages such as a leadless chip carrier (LCC), pin grid array (PGA) or charge-coupled device (CCD), because the bonding wires can become disconnected due to resonance during the cleaning process. Even if a device package allows ultrasonic cleaning, limit the duration of ultrasonic cleaning to as short a time as possible, since long hours of ultrasonic cleaning degrade the adhesion between the mold resin and the frame material. The following ultrasonic cleaning conditions are recommended:

Frequency: 27 kHz to 29 kHz
Ultrasonic output power: 300 W or less (0.25 W/cm^2 or less)
Cleaning time: 30 seconds or less

Suspend the circuit board in the solvent bath during ultrasonic cleaning in such a way that the ultrasonic vibrator does not come into direct contact with the circuit board or the device.

3.5.6 No Cleaning

If analog devices or high-speed devices are used without being cleaned, flux residues may cause minute amounts of leakage between pins. Similarly, dew condensation, which occurs in environments containing residual chlorine when power to the device is on, may cause between-lead leakage or migration. Therefore, Toshiba recommends that these devices be cleaned.

However, if the flux used contains only a small amount of halogen (0.05 W% or less), the devices may be used without cleaning without any problems.

3.5.7 Mounting Tape Carrier Packages (TCPs)

(1) When tape carrier packages (TCPs) are mounted, measures must be taken to prevent electrostatic breakdown of the devices.

(2) If devices are being picked up from tape, or outer lead bonding (OLB) mounting is being carried out, consult the manufacturer of the insertion machine which is being used, in order to establish the optimum mounting conditions in advance and to avoid any possible hazards.

(3) The base film, which is made of polyimide, is hard and thin. Be careful not to cut or scratch your hands or any objects while handling the tape.

(4) When punching tape, try not to scatter broken pieces of tape too much.

(5) Treat the extra film, reels and spacers left after punching as industrial waste, taking care not to destroy or pollute the environment.

(6) Chips housed in tape carrier packages (TCPs) are bare chips and therefore have their reverse side exposed. To ensure that the chip will not be cracked during mounting, ensure that no mechanical shock is applied to the reverse side of the chip. Electrical contact may also cause a chip to fail. Therefore, when mounting devices, make sure that nothing comes into electrical contact with the reverse side of the chip.
If your design requires connecting the reverse side of the chip to the circuit board, please consult Toshiba or a Toshiba distributor beforehand.

3.5.8 Mounting Chips

Devices delivered in chip form tend to degrade or break under external forces much more easily than plastic-packaged devices. Therefore, caution is required when handling this type of device.

(1) Mount devices in a properly prepared environment so that chip surfaces will not be exposed to polluted ambient air or other polluted substances.

(2) When handling chips, be careful not to expose them to static electricity.
In particular, measures must be taken to prevent static damage during the mounting of chips. With this in mind, Toshiba recommend mounting all peripheral parts first and then mounting chips last (after all other components have been mounted).

(3) Make sure that PCBs (or any other kind of circuit board) on which chips are being mounted do not have any chemical residues on them (such as the chemicals which were used for etching the PCBs).

(4) When mounting chips on a board, use the method of assembly that is most suitable for maintaining the appropriate electrical, thermal and mechanical properties of the semiconductor devices used.

*: For details of devices in chip form, refer to the relevant device's individual datasheets.

3.5.9 Circuit Board Coating

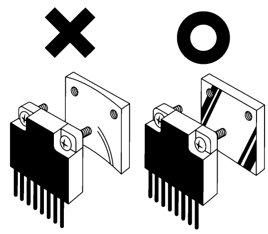
When devices are to be used in equipment requiring a high degree of reliability or in extreme environments (where moisture, corrosive gas or dust is present), circuit boards may be coated for protection. However, before doing so, you must carefully consider the possible stress and contamination effects that may result and then choose the coating resin which results in the minimum level of stress to the device.

3.5.10 Heat Sinks

(1) When attaching a heat sink to a device, be careful not to apply excessive force to the device in the process.

(2) When attaching a device to a heat sink by fixing it at two or more locations, evenly tighten all the screws in stages (i.e. do not fully tighten one screw while the rest are still only loosely tightened). Finally, fully tighten all the screws up to the specified torque.

(3) Drill holes for screws in the heat sink exactly as specified. Smooth the surface by removing burrs and protrusions or indentations which might interfere with the installation of any part of the device.



(4) A coating of silicone compound can be applied between the heat sink and the device to improve heat conductivity. Be sure to apply the coating thinly and evenly; do not use too much. Also, be sure to use a non-volatile compound, as volatile compounds can crack after a time, causing the heat radiation properties of the heat sink to deteriorate.

(5) If the device is housed in a plastic package, use caution when selecting the type of silicone compound to be applied between the heat sink and the device. With some types, the base oil separates and penetrates the plastic package, significantly reducing the useful life of the device. Two recommended silicone compounds in which base oil separation is not a problem are YG6260 from Toshiba Silicone.

(6) Heat-sink-equipped devices can become very hot during operation. Do not touch them, or you may sustain a burn.

3.5.11 Tightening Torque

(1) Make sure the screws are tightened with fastening torques not exceeding the torque values stipulated in individual datasheets and databooks for the devices used.

(2) Do not allow a power screwdriver (electrical or air-driven) to touch devices.

3.5.12 Repeated Device Mounting and Usage

Do not remount or re-use devices which fall into the categories listed below; these devices may cause significant problems relating to performance and reliability.

(1) Devices which have been removed from the board after soldering

(2) Devices which have been inserted in the wrong orientation or which have had reverse current applied

(3) Devices which have undergone lead forming more than once

3.6 Protecting Devices in the Field

3.6.1 Temperature

Semiconductor devices are generally more sensitive to temperature than are other electronic components. The various electrical characteristics of a semiconductor device are dependent on the ambient temperature at which the device is used. It is therefore necessary to understand the temperature characteristics of a device and to incorporate device derating into circuit design. Note also that if a device is used above its maximum temperature rating, device deterioration is more rapid and it will reach the end of its usable life sooner than expected.

3.6.2 Humidity

Resin-molded devices are sometimes improperly sealed. When these devices are used for an extended period of time in a high-humidity environment, moisture can penetrate into the device and cause chip degradation or malfunction. Furthermore, when devices are mounted on a regular printed circuit board, the impedance between wiring components can decrease under high-humidity conditions. In systems which require a high signal-source impedance, circuit board leakage or leakage between device lead pins can cause malfunctions. The application of a moisture-proof treatment to the device surface should be considered in this case. On the other hand, operation under low-humidity conditions can damage a device due to the occurrence of electrostatic discharge. Unless damp-proofing measures have been specifically taken, use devices only in environments with appropriate ambient moisture levels (i.e. within a relative humidity range of 40% to 60%).

3.6.3 Corrosive Gases

Corrosive gases can cause chemical reactions in devices, degrading device characteristics.

For example, sulphur-bearing corrosive gases emanating from rubber placed near a device (accompanied by condensation under high-humidity conditions) can corrode a device’s leads. The resulting chemical reaction between leads forms foreign particles which can cause electrical leakage.

3.6.4 Radioactive and Cosmic Rays

Most industrial and consumer semiconductor devices are not designed with protection against radioactive and cosmic rays. Devices used in aerospace equipment or in radioactive environments must therefore be shielded.

3.6.5 Strong Electrical and Magnetic Fields

Devices exposed to strong magnetic fields can undergo a polarization phenomenon in their plastic material, or within the chip, which gives rise to abnormal symptoms such as impedance changes or increased leakage current. Failures have been reported in LSIs mounted near malfunctioning deflection yokes in TV sets. In such cases the device's installation location must be changed or the device must be shielded against the electrical or magnetic field. Shielding against magnetism is especially necessary for devices used in an alternating magnetic field because of the electromotive forces generated in this type of environment.

3.6.6 Interference from Light (ultraviolet rays, sunlight, fluorescent lamps and incandescent lamps)

Light striking a semiconductor device generates electromotive force due to photoelectric effects. In some cases the device can malfunction. This is especially true for devices in which the internal chip is exposed. When designing circuits, make sure that devices are protected against incident light from external sources. This problem is not limited to optical semiconductors and EPROMs. All types of device can be affected by light.

3.6.7 Dust and Oil

Just like corrosive gases, dust and oil can cause chemical reactions in devices, which will adversely affect a device's electrical characteristics. To avoid this problem, do not use devices in dusty or oily environments. This is especially important for optical devices because dust and oil can affect a device's optical characteristics as well as its physical integrity and the electrical performance factors mentioned above.

3.6.8 Fire

Semiconductor devices are combustible; they can emit smoke and catch fire if heated sufficiently. When this happens, some devices may generate poisonous gases. Devices should therefore never be used in close proximity to an open flame or a heat-generating body, or near flammable or combustible materials.

3.7 Disposal of Devices and Packing Materials

When discarding unused devices and packing materials, follow all procedures specified by local regulations in order to protect the environment against contamination.

4. Precautions and Usage Considerations Specific to Each Product Group

This section describes matters specific to each product group which need to be taken into consideration when using devices.

4.1 Bipolar Ics

4.1.1 ICs for Use in Automobiles

(1) Design

⚠CAUTION

1) If your design includes an inductive load such as a motor coil, incorporate diodes into your design to prevent negative current from flowing in. Otherwise the device may malfunction or break down due to rush currents or counter electromotive force generated when the device is powered on and off. For information on how to connect the diodes, refer to the relevant individual datasheets for automobile ICs. Breakdown of the devices may result in injury.
2) Ensure that the power supply to any device which incorporates protective functions is stable. If the power supply is unstable, the device may operate erratically, preventing the protective functions from working correctly.
If protective functions fail, the device may break down, causing the device to explode and resulting in injury to the user.

- Heat radiation
  System power supply and driver ICs generate heat. When using these devices, refer to the technical databooks entitled Bipolar ICs for Use in Automobiles and General-Purpose Bipolar IC Databook, and incorporate sufficient heat radiation for the devices used into your design, so that the heat generated will not exceed the stipulated junction temperature (Tj) at which the ICs' internal heat-isolating protective circuits are activated.
- Power supply fuses
  These ICs contain various protective circuits to prevent them from breaking down due to faulty wiring or when pulses of noise are input to the power supply. However, should the IC break down, a large current may continue to flow. To prevent this, use a fuse of the appropriate capacity for the power supply.
  For information about the various types of protective circuit incorporated into the ICs, refer to the individual datasheets for the devices used.
- Power supply
  Do not abruptly increase or decrease the power supply to a device.

(2) Mounting

- Heat sinks

  Depending on the type of package used (e.g. an HSIP7-P-2.54), a device's characteristics may be degraded if the package is attached to a heat sink using screws. In such cases please consult Toshiba or a Toshiba distributor.

4.1.2 Communication Equipment ICs

(1) Design

When using these devices in power amps or system power supplies, be aware that since the effective current capacity of the output pins is 100 mA or higher, a device's DC output current may increase if there is any problem caused by an external component (in particular, leak current from a feedback resistor or a negative feedback capacitor). In some cases this will cause the product to generate heat or to catch fire. Take this into account when designing your product and choosing which components to use. For more detailed information, please refer to the individual datasheets or databooks.

(2) Mounting

Trends toward lightweight and compact design in mobile communications have resulted in the device-mounting board becoming vulnerable to distortion or deformation due to a lack of strength. This causes the devices to be imperfectly connected when mounted on the board. Therefore, carefully examine the board design and mounting methods to ensure that device pins are firmly connected to the board.

4.1.3 Audio/Video Equipment ICs

These devices are designed for use in consumer electronics, typically in television and audio equipment. When using these devices in low-frequency audio amps, system power supply ICs, driver ICs or power ICs, pay attention to the following points:

(1) Design

- Circuit design

  Large leakage current in input or negative feedback capacitors causes the DC output voltage of power ICs to increase. In this case, if the speaker's DC input withstand voltage is low, the speaker may emit smoke or catch fire.

  This must be fully taken into account when selecting the types of capacitor and speaker to use, especially in the case of power ICs of the BTL (bridge-tied load) connection type, in which the DC output voltage is input directly to the speaker.

- Heat radiation

  Power ICs, system power supply ICs and driver ICs generate heat. When using these devices, and incorporate sufficient heat radiation for the devices used into your design, so that the heat generated will not exceed the stipulated junction temperature (Tj = 150°C) at which the ICs' internal thermal shutdown protective circuits are activated. For more detailed information, refer to the individual product datasheets and to the general audio/car audio LSI databooks.

  Also, take into account the operating temperature ranges and characteristics of the peripheral components used with power ICs.

- Power supply fuses

  These ICs contain various protective circuits to prevent them from breaking down due to faulty wiring or noise pulses on the power supply input. However, should the IC break down, a large current may continue to flow. To prevent this, use a fuse of the appropriate capacity for the power supply.

4.1.4 ICs for Motors

(1) Design

- When designing a circuit incorporating a motor, be sure to incorporate a diode to act as a current-limiting resistance and to absorb any counter electromotive force so that the starting current or counter electromotive force does not cause any malfunction or breakdown in the IC. For detailed information concerning this type of design, refer to the relevant individual datasheets or databooks for ICs for motors.
- Circuits which are used to protect ICs from excessive current do not always work. If an IC is used outside its absolute maximum ratings, the IC may break down before the protective circuit is activated.
- Be sure to use a stable power supply for the IC. If the power supply is unstable, the internal circuits of the IC may function erratically, possibly causing the IC to break down.

(2) Heat radiation

- When using a driver IC, be sure to incorporate heat radiation so that the junction temperature (Tj) will never exceed 150°C. Since ICs generate considerable heat, ICs may break down if adequate heat radiation is not provided.
- Circuits which are used to protect devices from excessive heat do not always work. If an IC is used outside its absolute maximum ratings, it may break down before the protective circuit is activated.
- When attaching a heat sink to the driver IC, avoid excessive mechanical stress. Also note that some ICs inhibit the action of silicone rubber.
- When incorporating heat radiation or attaching heat sinks, refer to the relevant individual datasheets or databooks for ICs for motors.

(3) Power supply fuses

In order to prevent excessive current from flowing continuously when the IC breaks down, use a power supply fuse of an appropriate capacity. An IC may break down when used outside its absolute maximum ratings, or when wires or loads induce unusual pulse noise. The fuse capacity must be carefully determined in order to minimize any negative effect in the case of an IC breakdown and the resulting large current flow.

4.1.5 Cautions about Power Dissipation (Constant State)

A transistor by itself will often differ from a board- mounted transistor in its power dissipation characteristics. Changes in power dissipation for representative package types, due to board mounting, are described below.

Each representative package type and the power dissipation change is explained below.

4.1.5.1 Super-Mini Transistors

Allowable power dissipation of a super-mini transistor is 100 to 150 mW as a single unit.

However, when it is mounted on a ceramic board, this value increases depending on the board size. this is shown in Figure 4.1 (transistors used: 2SA1162 and 2SC2712).

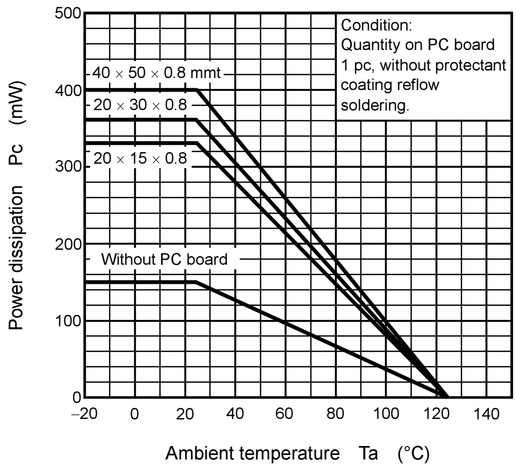


Figure 4.1 Pc (max) when Mounted on Alumi-Ceramic Board Ta Characteristic (2SA1162, 2SC2712)

4.1.5.2 Power-Mini Transistors

Since power-mini transistors are of compact size, Pc_{max} is only 500 mW; however, when they are mounted on a circuit board, thermal diffusion from a drain fin to the board will be high. The drain power dissipation will then range from 1.0 W to 2.0 W, and a circuit design capability equivalent to that of the TO-92MOD (800 to 900 mW) or TO-126 (1.0 to 1.2 W) is possible. Figure 4.2 shows the drain power dissipation for a typical case of circuit-board mounting of a 2SC2873 or 2SA1213.

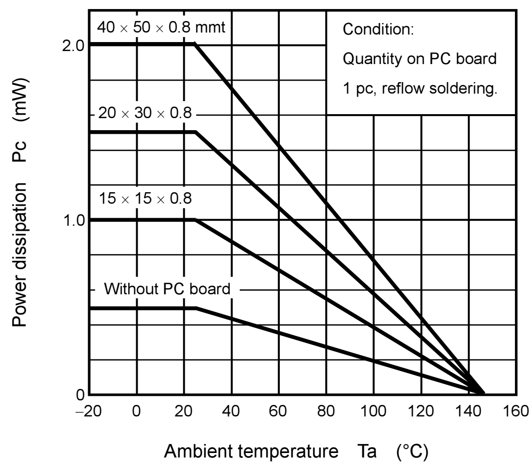


Figure 4.2 Pc (max) when Mounted on Alumi-Ceramic Board Ta Characteristic (2SC2873, 2SA1213)

4.1.5.3 Power-Mold Transistors

For straight-type power-mold transistors, the power dissipation (Pc) = 1 W However, when LB-type transistors have a drain-fin, their installed power dissipation increases significantly. When a power-mold transistor is soldered to an alumina-ceramic board, Pc (1) (1,000 mm^2) = 2 W, Pc (2) (2,500 mm^2) = 3 W Figure 4.3 show the relationship between drain power dissipation Pc and ambient temperature Ta for the transistors 2SC3074 and 2SA1244.

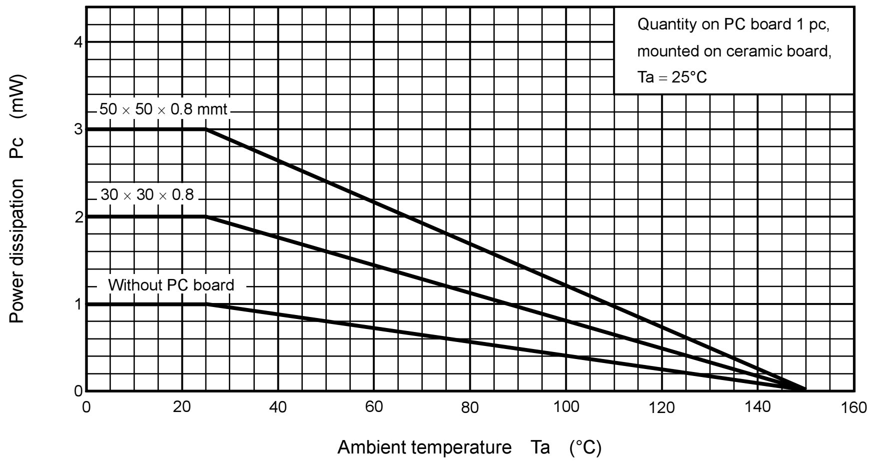


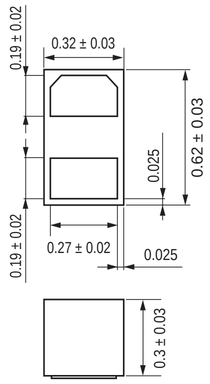
Figure 4.3 Power Dissipation Pc and Ambient Temperature Ta when Transistors are Mounted on Alumina-Ceramic Boards (for 2SC3074 and 2SA1244 devices)

[9]　Package Dimensions

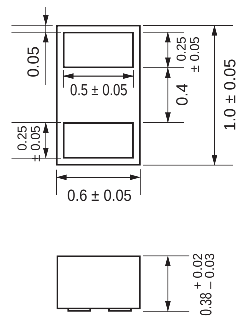
[9] Package Dimensions

Unit: mm

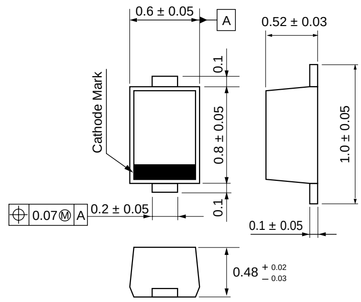
SC2



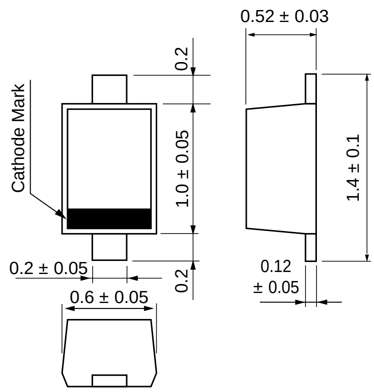
CST2



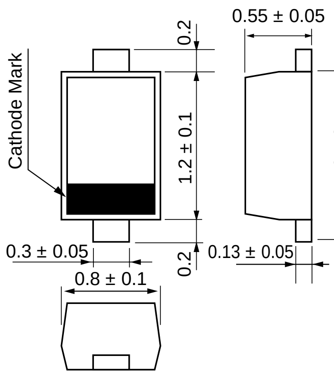
fSC



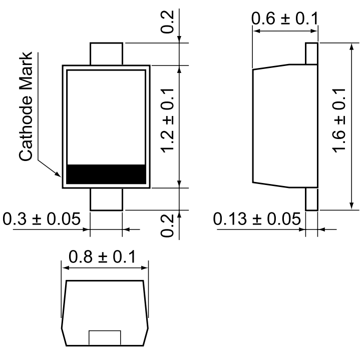
sESC



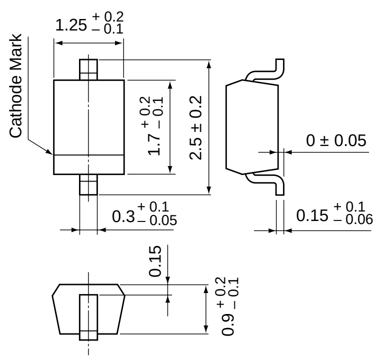
TESC



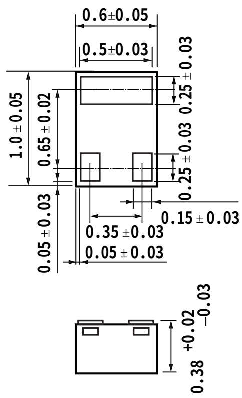
ESC



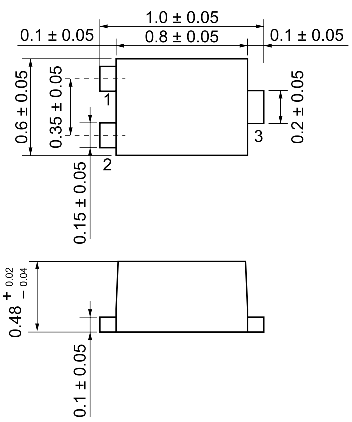
USC



CST3

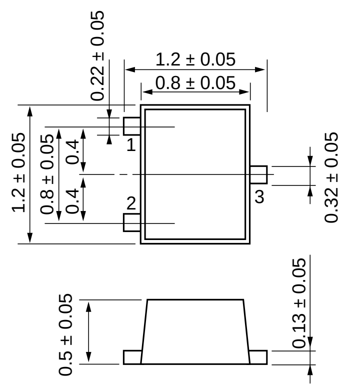


fSM

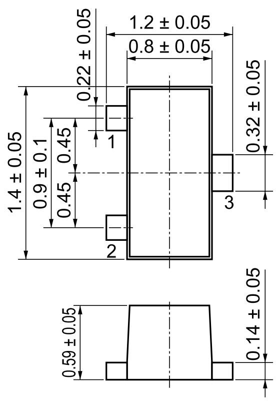


Unit: mm

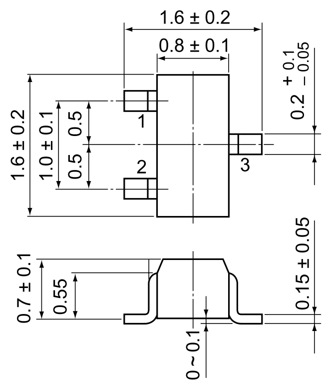
VESM



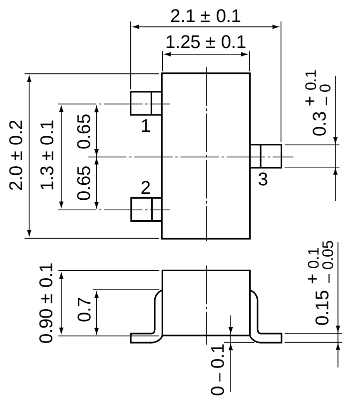
TESM



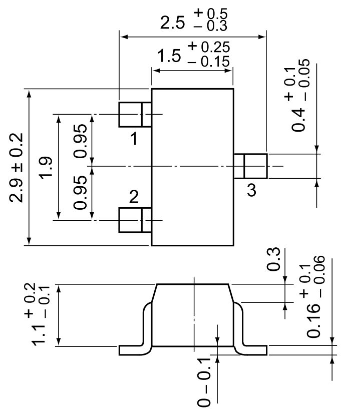
SSM



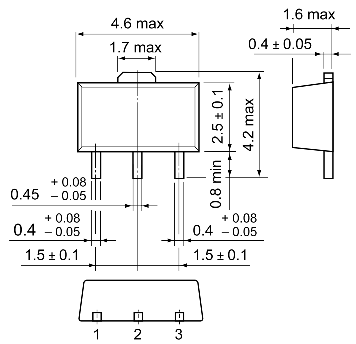
USM



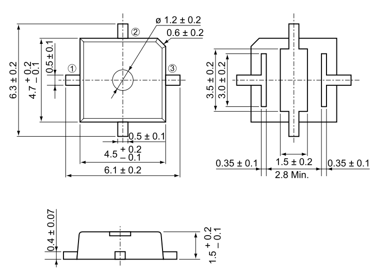
S-MINI



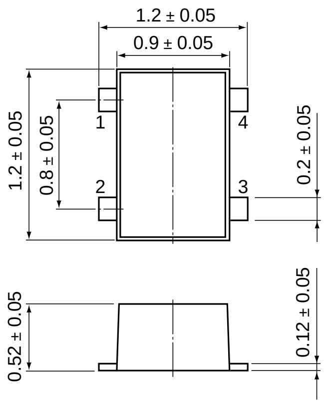
PW-MINI



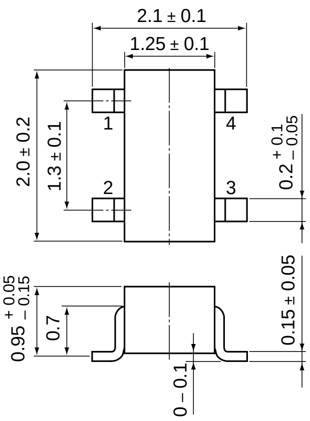
PW-X



TESQ

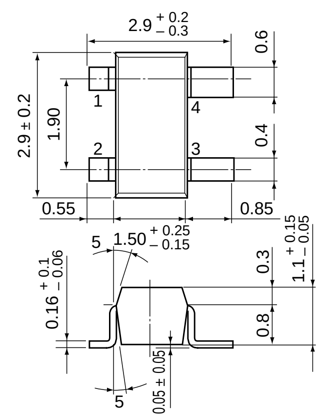


USQ

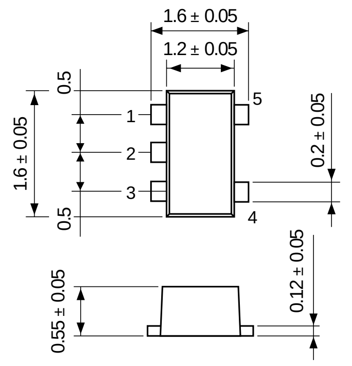


Unit: mm

SMQ



ESV



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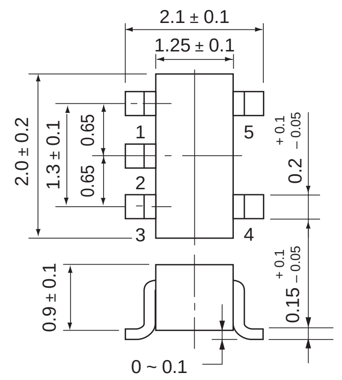
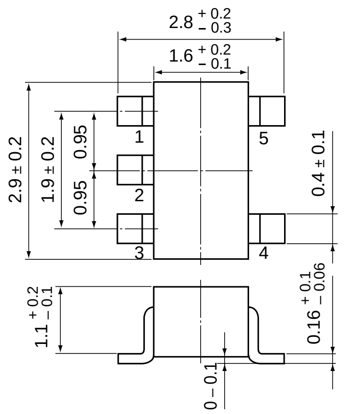
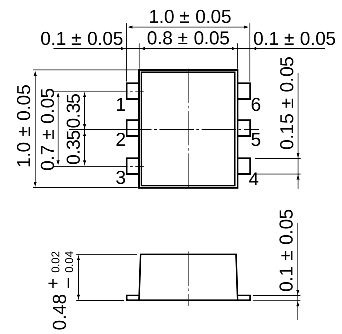


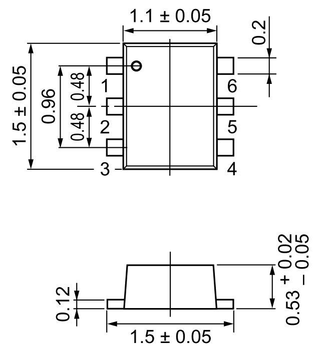
SMV



fS6



sES6



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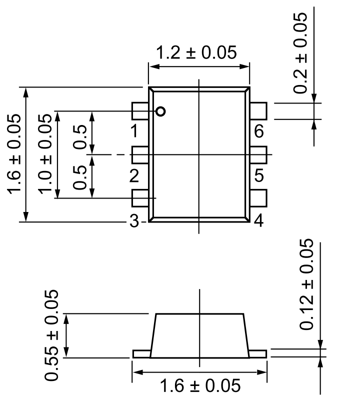

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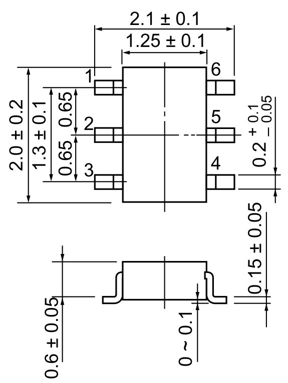

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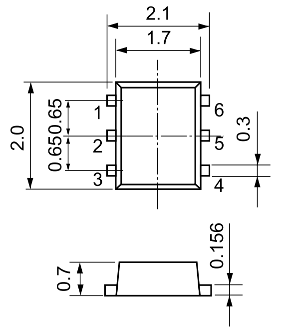
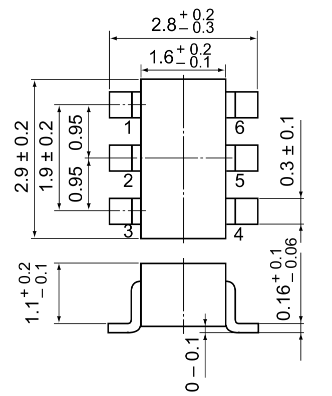
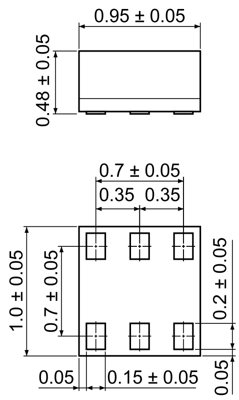


Unit: mm

SM6



CS6



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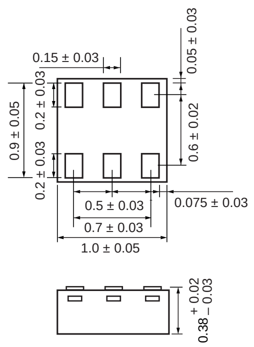

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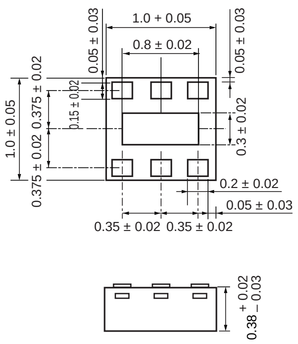
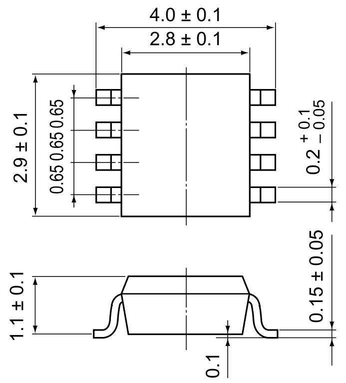


SM8



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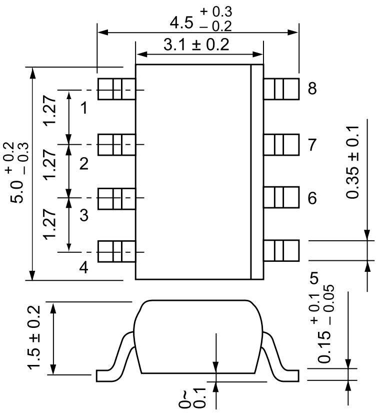

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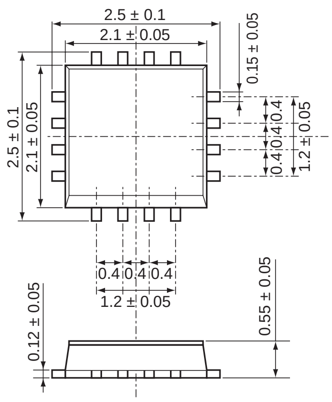

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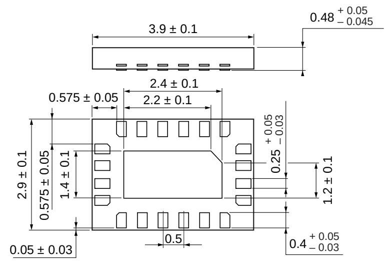
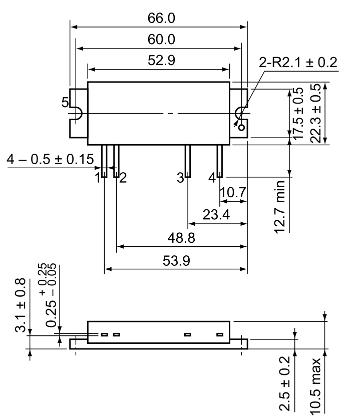
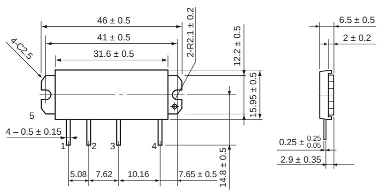


5-53P



Unit: mm

5-32F



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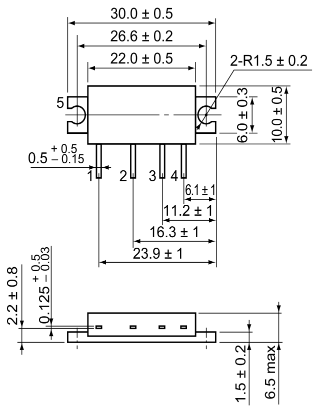
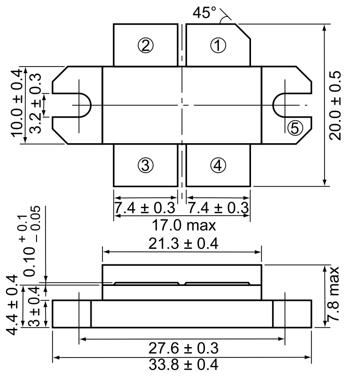
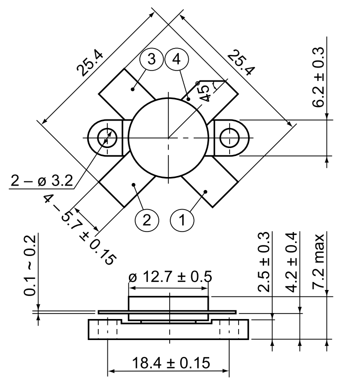


2-22C2A



2-13B1A



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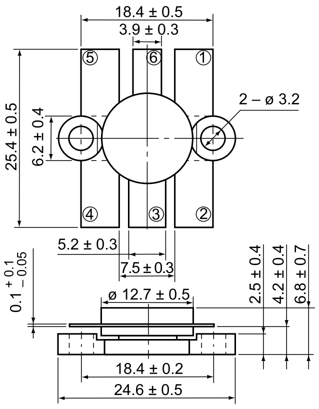

[10] List of Final-Phase Products

[10] List of Final-Phase Products

The following listed products will soon be discontinued. Refer to the recommended replacement devices in the adjacent column.

Final-Phase Products

Part Number	Recommended Replacement	Part Number	Recommended Replacement	Part Number	Recommended Replacement
1S2186	1SS341	2SC5313	—	MT6P03AE	—
1S2236	1SV160	2SC5317	MT3S07T	MT6P03AT	—
1SS238	1SS312, 1SS314	2SK3179	—	MT6P04AE	—
1SS239	1SS154, 1SS271	3SK240	—	MT6P04AT	—
1SS241	1SS314, 1SS381	3SK250	—	S-AU26	—
1SS242	1SS315, 1SS295	3SK274	—	S-AU27AL	S-AU83L
1SV149	—	3SK283	—	S-AU27AM	S-AU83H
1SV153	1SV214	3SK284	—	S-AU27AH	S-AU83H
1SV153A	—	3SK320	—	S-AU35AH	—
1SV161	1SV215	3SK59	3SK126	S-AV6	S-AV35
1SV186	1SV245	HN3C07F	—	S-AV7	S-AV33
1SV204	1SV216	HN3C08F	—	S-AV10L	S-AV33
1SV211	1SV262	HN3C10F	—	S-AV10H	S-AV33
1SV212	1SV229	HN3C13FU	—	S-AV17	S-AV36
1SV217	1SV262	HN3C14FT	—	S-AV22A	—
1SV224	1SV230	HN9C02FT		TA4006F	—
JDV2S10T	JDV2S10S	HN9C03FT		TA4007F	—
2SC2348	—	HN9C07FT	—	TA4008F	TA4011FU, TA4011AFE
2SC2509	—	HN9C10FT	—	TA4009F	TA4012FU, TA4012AFE
2SC2548	—	HN9C13FT	—	TA4011F	TA4011FU, TA4011AFE
2SC2644	—	HN9C16FT	—	TA4012F	TA4012FU, TA4012AFE
2SC3011	—	HN9C18FT	—	TA4013FU	—
2SC3122	—	HN9C19FT	—	TA4102F	—
2SC3602	—	HN9C21FT	—	TA4103F	—
2SC3662	—	HN9C22FT	—	TA4300F	—
2SC3745	—	MT3S01T	MT3S11T	TA4301F	—
2SC3828	—	MT3S02T	MT3S11T	TG2000F	—
2SC4200	—	MT3S31T	—	TG2003V	—
2SC4201	—	MT3S46T	—	TG2202F	—
2SC4249	—	MT3S46FS	—	TG2205F	TG2216TU
2SC4255	2SC4252	MT4S34U	—	TG2206F	TG2216TU
2SC4392	2SC5107	MT6L69FS	—		
2SC5312	—	MT6L70FS	—		

[11] List of Discontinued Products

[11] List of Discontinued Products

The following listed products have been discontinued. Refer to the recommended replacement devices in the adjacent column.

Discontinued Products

Part Number	Recommended Replacement	Part Number	Recommended Replacement	Part Number	Recommended Replacement
1S2094	—	2SC389A	2SC1923	2SC2783	—
1S2187	1SS315	2SC390	2SC2347	2SC2805	2SC3121
1SS42	—	2SC391	2SC2347	2SC2876	2SC5087
1SS148	—	2SC391A	2SC2347	2SC3006	—
1SS155	1SS314	2SC392	2SC2498	2SC3147	—
1SS240	—	2SC392A	2SC2347	2SC3301	2SC3607
1SV100	—	2SC393	—	2SC3302	2SC5087
1SV123	1SV214	2SC396	2SC1923	2SC3445	2SC5084
1SV158	1SV215	2SC397	2SC2347	2SC3608	MT4S04
1SV226	1SV288	2SC784	2SC1923	2SC4316	2SC5089
1SV238	1SV269	2SC784TM	2SC1923	2SC4318	—
1SV255	—	2SC784TMA	2SC1923	2SC4319	MT4S03
1SV256	1SV216	2SC785	2SC1923	2SC4323	2SC5097
1SV257	1SV279	2SC786	2SC1923	2SK19	2SK192A
1SV258	—	2SC787	—	2SK19TM	2SK192A
1SV260	1SV280	2SC864	2SC383TM	2SK61	2SK161
1SV261	1SV309	2SC941	2SC941TM	2SK61LV	2SK161
1SV274	1SV282	2SC1236	2SC5084	2SK192	2SK192A
1SV275	1SV283	2SC1558	2SC5087	2SK1028	—
2SC381TM	2SC1923	2SC1559	2SC5087	2SK1310	2SK1310A
2SC381TMA	2SC1923	2SC1743	2SC5087	2SK1739	2SK1739A
2SC382	—	2SC2099	—	2SK2496	—
2SC382TM	—	2SC2114	—	2SK2497	—
2SC384	2SC1923	2SC2115	—	2SK2856	—
2SC385	2SC2349	2SC2328	—	2SK3276	—
2SC385A	2SC2349	2SC2395	—	3SK22	—
2SC385ATM	2SC2349	2SC2531	—	3SK23	2SK192A
2SC386	2SC2349	2SC2638	—	3SK28	2SK192A
2SC386A	2SC2349	2SC2639	—	3SK73	3SK195
2SC387	2SC2347	2SC2640	—	3SK77	—
2SC387A	2SC2347	2SC2641	—	3SK78	3SK195
2SC387A (G)	2SC2347	2SC2642	—	3SK90	—
2SC387A (G) TM	2SC2347	2SC2643	—	3SK101	3SK195
2SC387ATM	2SC2347	2SC2652	—	3SK102	—
2SC389	2SC1923	2SC2663	2SC5087	3SK112	—

Part Number	Recommended Replacement	Part Number	Recommended Replacement	Part Number	Recommended Replacement
3SK114	3SK126	S1255	2SC2644	S-AV24	—
3SK115	3SK291	S1256	2SC2644	S-AV26H	—
3SK121	—	S1297	2SC2498	S-AV28	—
3SK140	—	S2531	2SC2498	S-AV29H	—
3SK145	3SK291	S2676	—	S-AV30H	—
3SK146	3SK232	S9A61	—	TG2002V	—
3SK152	3SK292	S-AU6L	—	TG2005F	TG2006F
3SK159	3SK292	S-AU6VL	—	TG2200AF	TG2216TU
3SK160	3SK225	S-AU39	—	TG2200F	TG2216TU
3SK198	3SK291	S-AU64	—	TG2203F	TG2210FT
DLP238	1SS314	S-AU80	—	TG2204F	TG2216TU