Application Note AN55132B

Design of LOW COST High Isolation 20W and 50W Transmit and Receive Antenna Switches

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DESCRIPTION

This paper describes a high isolation 20 W transmit and receive antenna switch for use in 500 MHz to 4 GHz wireless infrastructure applications such as cellular GSM, CDMA, 3G and 4G-WCDMA, TD-SCDMA; 802.11a, 802.11b, 802.11g WLAN / WiFi; WiMax; ATSC and DVB-T Digital TV; and others using low cost high performance discrete MSWSSB-020-40 (D1 and D3) series-shunt and MEST^{2}G-020-15 (D2) series heat-shunt PIN diode switch components. On the receive side, the circuit uses a 2 GHz quarter wave transmission line between the two series-shunt elements and on the transmit side it uses a single series. It was optimized over the 500 MHz to 3.8 GHz bandwidth. It requires no negative supply voltage. It uses 0.020 inch thick Rogers RO4350B substrate material with 1 oz copper clad and the component values and part numbers can be found in table 2.

At high power levels greater then 5 watts, the reverse bias voltage values shown in figure 1 will need to be increased. For example, at 20W and 500 MHz, the reverse bias voltage will need to be greater then 45 volts.

In the transmit mode and with 50 mA bias, the circuit provides the following performance over the 500 MHz - 3.8 GHz bandwidth: less then 0.75 dB insertion loss, better then 17 dB transmitter port return loss and less then 48 dB antenna-to-receiver isolation.

In the receive mode, with 50 mA bias and in the frequency bands of most interest; the circuit provides the following performance over the 500 MHz to 3.8 GHz bandwidth: less then 0.8 dB insertion loss, better then 16 dB antenna port return loss and an antenna-to-transmitter isolation of 27 dB at 2 GHz and 20 dB at 3.8 GHz.

The 50 W design can be accomplished with similar performance as the 20W design by changing the D2 diode. This design concept is very versatile and can accompany different power levels and frequency bands by changing the D2 switch diode. Please refer to the Switch Elements Matrix Table 3 for proper choice of D2, D1 and D3.

Table 1. 0.5 - 3.5 GHz Typical Performance 50 mA

Mode	Parameter	1 GHz	2 GHz	3.5 GHz
Tx	Insertion Loss Return Loss Isolation	0.5 17 70	0.5 19 62	0.7 30 62
Rx	Insertion Loss Return Loss Isolation	0.45 29 31	0.55 23 26	0.7 19 20

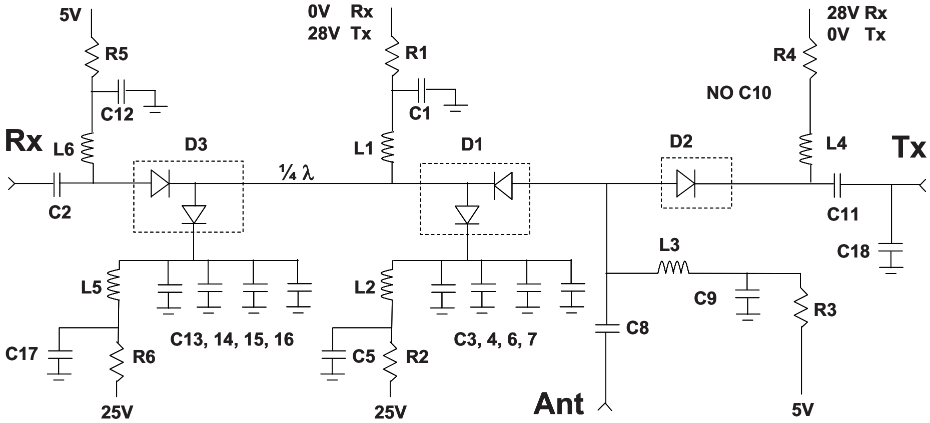

Figure 1. Schematic Diagram

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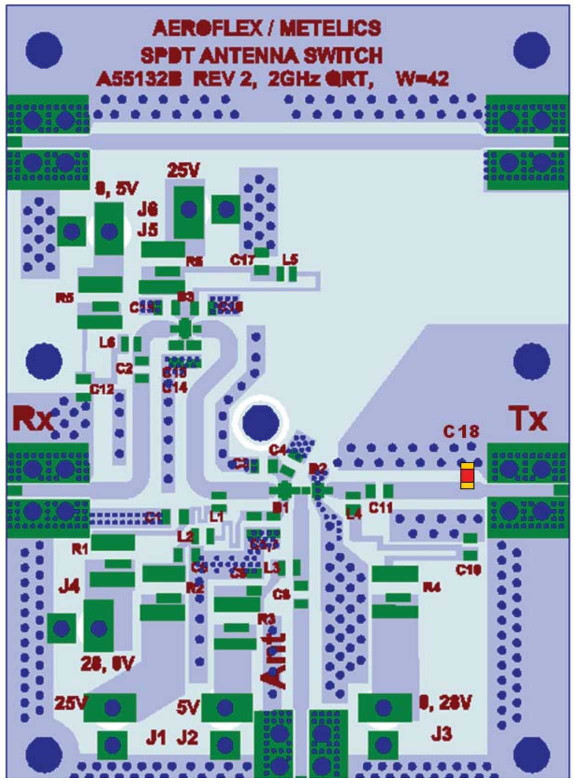
Revision Date: 10/12/2011

BOARD OUTLINE AND DIMENSIONS



Dimensions: 1.50 in (3.81 cm) x 2.10 in (5.33 cm)

Table 2. Parts List

Component	QTY	Description	Manufacture	P/N
R1, R4	2	0 Ω, 1 Amp, 0603 pkg	KOA Speer or equivalent	RK73Z1JTTE
R2, R6	2	100 Ω, 1/10 W, 0603 chip Resistor, ±5%	KOA Speer or equivalent	RK73B1JTTE101J
R3, R5	2	82 Ω, 1/2 W, 1210 chip Resistor, ±5%	KOA Speer or equivalent	RK73B2ETTE820J
C3, C15	2	10 pF, 250 VDC Capacitor, 0603 pkg	ATC	600S100JW 250XT
C2, C8, C11	3	15 pF, 250VDC Capacitor, 0603 pkg	ATC	600S150JW 250XT
C6, C7, C13, C14	4	47pF, 250VDC Capacitor, 0603 pkg	ATC	600S470JW 250X
C1, C4, C5, C9, C12, C16, C17	7	100 pF, 250VDC Capacitor, 0603 pkg	ATC	600S101JW 250XT
C18	2	0.2 pF, 250VDC Capacitor, 0603 pkg	ATC	600S0R2AW 250XT
L1 thru L6	6	47 nH, 600mA chip Inductor, 0603 pkg	Coilcraft	0603CS-47NXGLW
T1 thru T5	5	RF coax to co-planar edge connector	Johnson-Emerson	142-0761-831
J1 thru J6	6	Break Away Header on 0.100 centers	MOLEX or equivalent	22-28-4363
D2	1	Series PIN Diode in 2012 pkg	Aeroflex / Metelics	MEST2G-020-15
D1, 3	2	Series-Shunt PIN Diodes in 2012 pkg	Aeroflex / Metelics	MSWSSB-020-30
PCB	1	SPDT 2GHz QRT-W Ant SW Demo BD	Aeroflex / Metelics	A55132B, rev 2

Application Note
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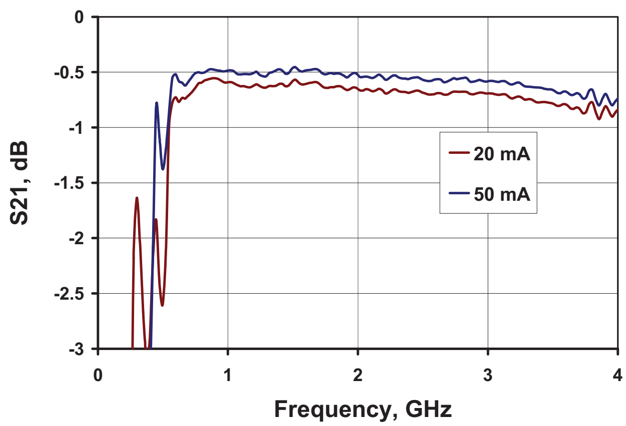
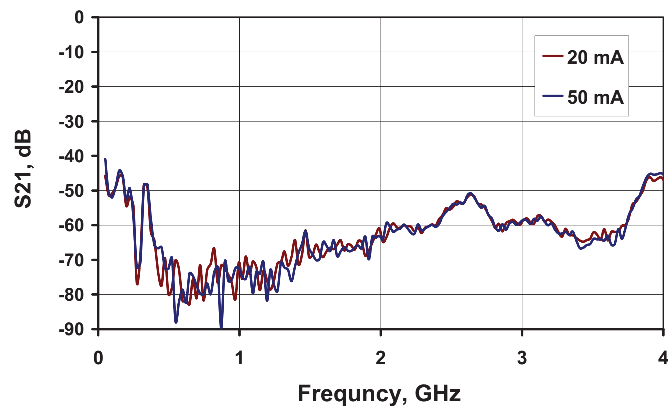
Typical RF Performance at T_A = 25 °C, Zo = 50 Ω, Small Signal P = -10 dBm

TRANSMIT MODE

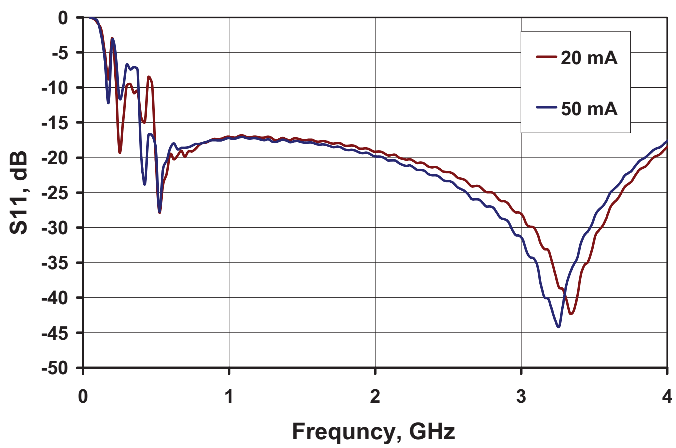
Insertion Loss, Ant-Tx



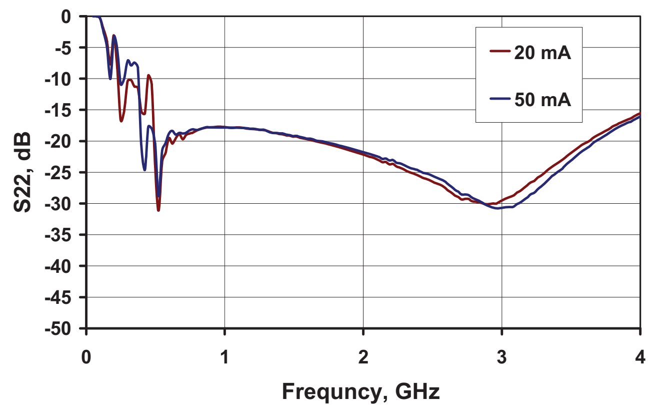
Isolation, Ant-Rx



Return Loss, Tx Port



Return Loss, Ant Port



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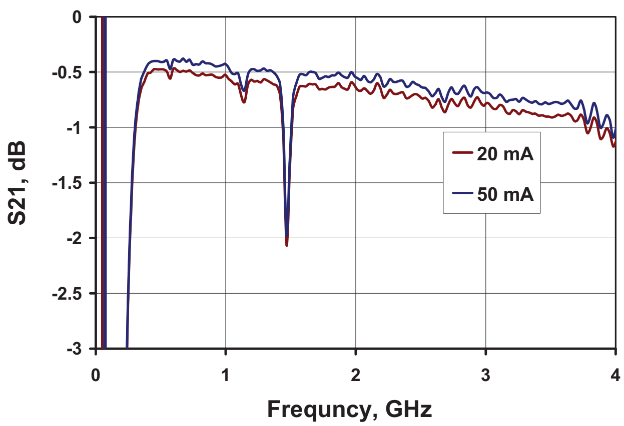
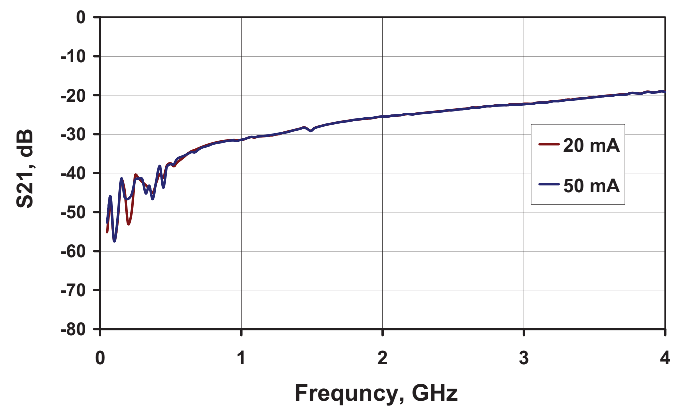
RECEIVE MODE

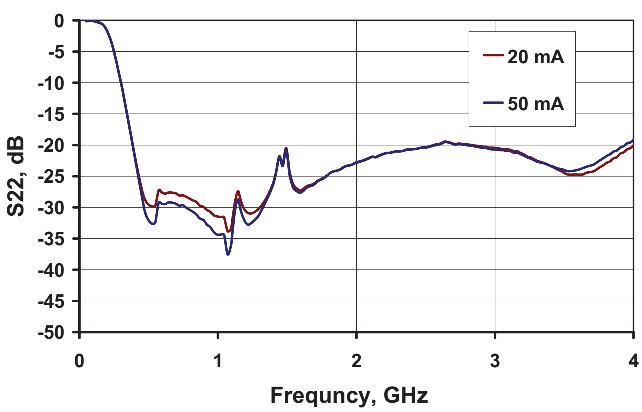
Insertion Loss, Ant-Rx



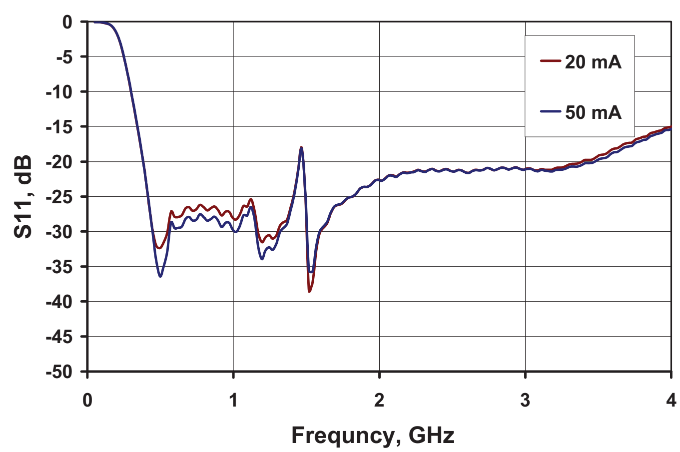
Isolation, Ant-Tx



Return Loss, Rx Port



Return Loss, Ant Port



Revision Date: 10/12/2011

Table 3. Summary of Aeroflex / Metelics' Surface Mount Switch Elements Products

Part Number	Configuration	Maximum Power Watts	Insertion Loss				Isolation				Return Loss			
			1.0	2.0	3.5	5.8	1.0	2.0	3.5	5.8	1.0	2.0	3.5	5.8
MEST^{2}G-010-20	Series 2012	10	0.30	0.30	0.35	0.35	31	26	20	18	30	30	20	17
MEST^{2}G-020-15	Series 2012	20	0.20	0.20	0.25	0.30	26	20	15	12	29	27	29	20
MEST^{2}GFC-010-25	Series Chip	10	0.25	0.25	0.25	0.25	34	28	23	19	31	30	28	25
MEST^{2}G-080-25	Series CM27	80	0.20	0.22	0.25	0.45	30	25	20	18	30	30	22	14
MEST^{2}G-150-20	Series CM26	150	0.20	0.25	0.30	0.40	26	21	17	13	30	34	16	17
MSWSE-005-15	Series 0503	4	0.20	0.21	0.28	0.48	24	18	14	11	32	28	22	14
MSWSE-010-15	Series 0503	10	0.25	0.25	0.25	--	17	12	7	--	22	27	25	--
MSWSE-010-16S	Series 0402P	10	0.05	0.08	0.10	--	21	15	11	--	34	29	25	--
MSWSE-20-05	Series 0503	20	0.03	--	--	--	9	--	--	--	37	--	--	--
MSWSE-040-10	Series 0805P	40	0.10	0.10	0.20	--	19	14	8	--	34	24	18	--
MSWSE-044-10	Series 0805P	40	0.12	0.20	0.35	--	15	10	5	--	39	30	19	--
MSWSE-050-10	Series 0805P	70	0.10	--	--	--	13	--	--	--	30	--	--	--
MSWSE-050-17	Series 0805P	40	0.05	0.06	--	--	19	12	--	--	30	25	--	--
MSWSER-070-10	Series 3023	80	0.04	--	--	--	8	--	--	--	22	--	--	--
MSWSER-100-05	Series 3023	80	0.21	--	--	--	10	--	--	--	24	--	--	--
MSWSH-020-30	Shunt 2012	20	0.05	0.10	0.20	0.35	35	32	30	28	34	25	18	15
MSWSH-040-30	Shunt 2012	40	0.03	0.07	0.12	0.28	37	34	30	26	30	24	20	15
MSWSH-100-30	Shunt CM22	300	0.10	0.12	0.20	0.32	33	30	30	28	30	24	20	15
MSWSHB-020-30	Shunt 2012	40	0.08	0.10	0.15	0.20	38	42	35	30	35	38	35	28
MSWSHC-040-40	Shunt 2615	40	0.10	0.18	0.22	0.38	40	50	52	53	30	27	22	19
MSWSS-020-40	Series Shunt 2012	20	0.15	0.20	0.35	0.55	63	52	45	35	30	25	18	13
MSWSS-040-30	Shunt Series 2012	20	0.09	0.11	0.13	0.18	58	50	43	36	38	35	33	30
MSWSSB-020-30	Series Shunt 2012	20	0.20	0.25	0.30	0.40	70	60	50	35	35	40	25	25

Thermal Considerations

For long term reliability, the maximum diode junction temperature should never be exceeded; therefore, if the circuit is going to operate at the maximum transmit power rating, then thermal design issues and possible heat sinking requirements need to be considered. To calculate junction temperature, the power dissipation of the series diode (D2) and the combined thermal resistance of the diode, circuit board and heat sink need to be known.

This analysis starts from the diode junction and ends at the heat sink. The heat sink design is left to the design engineer, since system requirements may vary depending on the specifics of the application and environment.

In the transmit mode, the MEST^{2}G-020-15 series diode power dissipation is equal to the input power minus the reflected power (RL) and the insertion loss (IL) which are both a function of frequency. At 2 GHz, the MEST^{2}G-020-15 insertion loss is 0.2 dB [1].

Mathematically and neglecting RL,

$P_{dis} = P_{in} - P_{out}$ (W) (1)

$P_{in} = 20$ W → 43 dBm

Need to calculate P_{out} (W),

$P_{out} = P_{in} -$ Insertion Loss (2)

$= 43$ dBm − 0.2 dB

$= 42.8$ dBm → 19.05 W

Then,

$P_{dis} = 20 - 19.05 = \underline{0.95\ W}$

Given the maximum junction temperature, power dissipation and junction-to-case diode thermal resistance; the maximum top-of-board temperature just below the metal belly of the 2012 package can be calculated. Referring to the data sheet, the MEST^{2}G-020-15 junction-to-case (2012 package ground lead) thermal resistance is 65 °C/W and the maximum junction temperature is 175 °C [1].

Mathematically,

$T_J = T_{board} + P_{dis} \times \theta_{JC}$ (3)

$= T_{board} + 61.8$ °C

Keep $T_J < 175$ °C then from equation 3,

$T_{board} < TJ - P_{dis} \times \theta_{JC}$ (4)

$< 175 - 61.8$ °C

$< \underline{113.2\ °C}$

Goal: Keep top of board temperature under 2012 package below this value

Looking at the diode by itself and from equation 3, the de-rating curve shown in Figure 3 can be referenced for board and heat sink thermal designs.

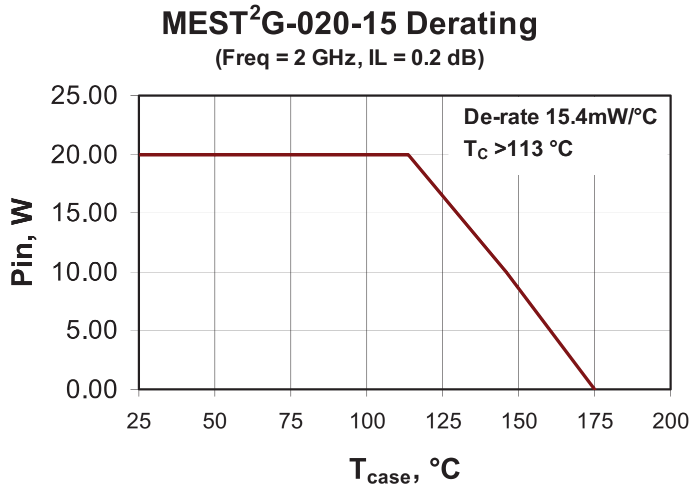


Figure 3

Figure 4 below is another way of viewing the same information and can be used to track junction temperature. In this figure, the case temperature is held steady at 25 °C.

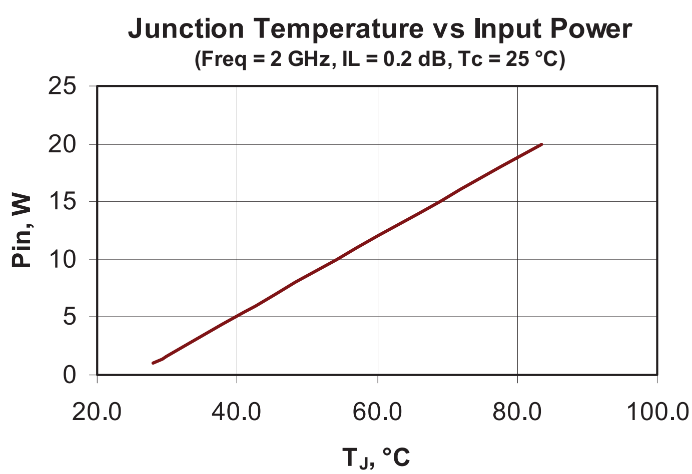


Figure 4. Junction temperature versus Pin while holding case temperature at 25 °C

Thermal Resistance Model and θ_{BH} Calculation

The thermal resistance from the top of the board to the heat sink for this circuit is primarily determined by the two solder filled via holes just beneath the metal belly of the 2012 package and the two non-solder filled via holes just adjacent to the package foot print as shown in Figure 6. The diameter of the via holes are 0.010 inches and for this example use 96.5Sn-3.5Ag solder whose thermal conductivity is 0.33 W/cm-C (0.84 W/in-C [2]. The via walls are plated with 1 oz copper (0.0014 inches) and the thermal conductivity for copper is 4 W/cm-C (10.2 W/in-C) [3]. The height of the board is 0.020 inches.

Mathematically and for a solder filled via,

$\theta_{SF\_via} = \theta_{solder}$ in parallel with θ_{copper} (5)

Where,

$\theta_{solder} = L / (A \times \sigma_{solder})$ (6)

$= L / (\pi r^2 * \sigma_{solder})$ (7)

$r_{solder} = 0.005 - 0.0014,$

$\theta solder = 0.02 / (\pi * 0.0036^{\wedge}2 * 0.84)$

$= \underline{585\ °C / W}$

Cross sectional area of copper going down via walls,

$Acopper = A_{OD\_hole} - A_{ID\_copper\_wall}$ (8)

$= \pi r_h^2 - \pi r_s^2$ (9)

$= \pi (0.005^{\wedge}2 - 0.0036^{\wedge}2)$

$= 3.78E\text{-}5 \ in^2$

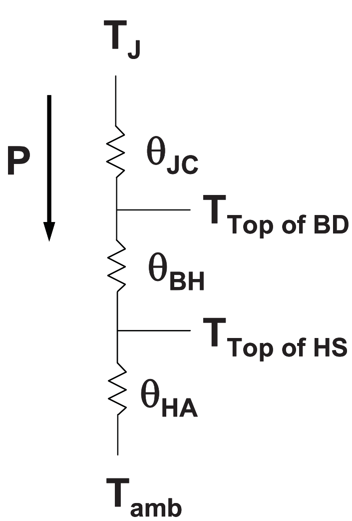


Figure 5. Thermal resistance model.

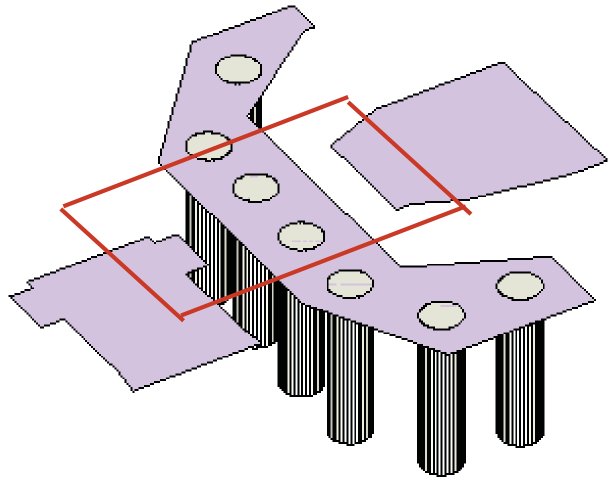


Figure 6. 2012 pkg foot print over PCB vias.

θ_{copper},

$\theta_{copper} = L / (A \times \sigma_{COPPER}2)$ (10)

Now solve for θ_{copper},

$\theta copper = 0.02 / (3.78E\text{-}5 * 10.2)$

$= \underline{52\ °C / W}$

Now calculate θ_{SF_VIA} from equation 4,

θ_{SF_VIA} = 52 in parallel with 585

$= \underline{48\ °C / W}$

To calculate board-to-heat sink thermal resistance, θ_{BH}, have two solder filled vias and 2 unfilled 1 oz copper plated vias all in parallel,

$\theta_{BH} = (\theta_{SF\_VIA} \,||\, \theta_{SF\_VIA}) \,||\, (\theta_{CU} \,||\, \theta_{CU})$ (11)

$= (48 \,||\, 48) \,||\, (52 \,||\, 52)$

$= \underline{12.5\ °C / W}$

Combining the diode junction-to-case thermal resistance with the board thermal resistance,

$\theta_{JH} = (\theta_{JC} + \theta_{BH})$ (12)

$= 65 + 12.5$

$= \underline{77.5\ °C / W}$

And again, to keep $T_J < 175$ °C and using a modified form of equation 3,

$THS < T_J - P_{dis} \times \theta_{JH}$ (13)

$< 175 - 73.6$ °C

$\underline{< 101\ °C}$

Application Note
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If using this board in combination with the MEST2G-020-15 and if operating the transmitter at the maximum power level, then the temperature between the board and heat sink (THS) needs to be kept below the final number calculated above. This number, the power dissipation and the maximum ambient temperature will determine the heat sink requirements as shown in equation 14 below.

$$\theta_{HA} < \frac{(T_J - P_{dis}(\theta_{JC} + \theta_{BH})) - T_{AMB\_max}}{Pdis} \quad (14)$$

Equations 12 & 13 have already been solved,

$$\theta_{HA} < \frac{101 - T_{AMB\_max}}{P_{dis}}$$

SUMMARY

A 20W and 50W 500 MHz to 4 GHz antenna transmit and receive generic switch design has been presented that uses Aeroflex-Metelics' low cost high performance discrete MSWSS-020-40 series-shunt and MEST2G-020-15 shunt PIN diode switch elements. The 20W design provides very low insertion loss along with high antenna-to-receiver isolation making it ideal for most wireless infrastructure applications. In addition, a thermal analysis was provided that shows that this switch design can conservatively handle its maximum rated power provided sufficient heat sinking is incorporated into the system design.

REFERANCES

[1] Aeroflex Metelics Inc., "MEST2G-020-15 Data Sheet"

[2] Microwaves101.com, "Solder for Microwave Assemblies"

[3] The Engineering Tool Box, "Thermal Conductivity of Some Common Materials"

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