MITEL SEMICONDUCTOR

Application Note **MSAN-169**

An Input Selection Circuit for the MT8843 and MT88E43

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Contents

Abstract

This application note describes a low cost circuit to select the MT8843 and MT88E43 analog input between tip/ring and the hybrid receive pair in a CIDCW telephone using passive components and transistors only. By connecting the MT8843/E43 to the hybrid receive pair in the CAS detection state, the CPE's CAS detection speech immunity can be improved significantly.

Introduction

One of the applications of the MT8843 and MT88E43 is in telephones which support the Calling Identity Delivery on Call Waiting (CIDCW) feature offered by North American phone companies. These CPEs are known as Type 2 CPEs. In such CPEs the MT8843/E43 can be used to detect the dual tone CPE Alerting Signal (CAS) and to demodulate the FSK signal containing the CIDCW data.

Successful CAS detection poses a big challenge to CPE designers. CAS must be detected in the presence of near end speech, such as when the user is speaking when the CAS is sent from the central office. The detector must also be immune to false detections caused by speech from both the near end and the far end. These performances are known as the talkdown and talkoff speech immunity respectively.

CIDCW signalling occurs while the phone is off hook, whereas Caller ID signalling occurs while the phone is on hook. A Type 2 CPE must be able to receive both on hook and off hook signalling.

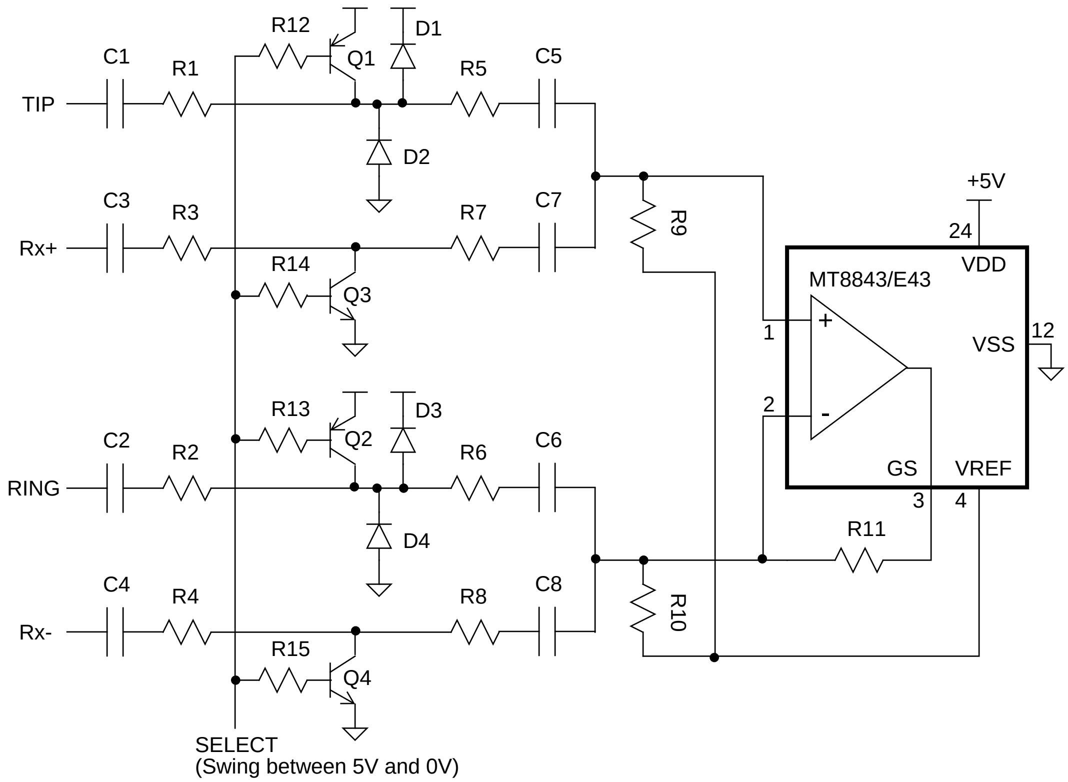
When the CPE is a telephone instead of an adjunct unit, CAS speech immunity can be improved by connecting the MT8843/E43 to the receive pair of the telephone hybrid when the phone is off hook. When on hook, the MT8843/E43 should be connected to tip/ring because either the hybrid is non-functional or the signal level has been severely attenuated at the hybrid receive pair during the on hook state.

The hybrid is a 2 to 4 wire interface circuit. The 2 wire side is connected to tip and ring of the phone line. The 4 wire side consists of the transmit and receive pairs. The transmit pair is connected to the microphone. The receive pair is connected to the speaker. Ideally the receive pair should contain signal from the far end only. But some near end speech is present on the receive pair because of the imperfect match between the hybrid's line balancing impedance and the telephone line.

By connecting the MT8843/E43 to the receive pair, talkdown immunity is improved because the near end speech level is reduced compared to tip/ring while the level of the CAS from the central office is the same as on tip/ring. Near end talkoff also improves because the near end speech level is reduced. Since most talkoff hits are caused by near end speech, improving near end talkoff greatly improves the overall talkoff immunity.

One way to select between tip/ring and the hybrid receive pair is with a double pole double throw relay. Another is to use an op-amp to convert the differential tip/ring signal to single ended (i.e. referenced to circuit ground) and then use analog switches to select between the single end converted tip/ring and the hybrid receive output. Both solutions are expensive.

This note describes a low cost circuit using passive components and bipolar transistors only. For some hybrids the 4 wire side is single ended. That is, the transmit and receive signals are referenced to circuit ground. This article describes both the case where the receive pair is balanced (differential) and the single ended case.



Unless stated otherwise, resistors are 1%, 0.1Watt; capacitors are 5%, 6.3V.

For 1000Vrms, 60Hz isolation from Tip to Earth and Ring to Earth:

R1,R2	470K, 1W, 5%, 1KV (e.g. IRC Type GS-3)	C1,C2	4n7, 1100V minimum

For FCC Part 68 Type B Ringing:

R1,R2	475K, 0.1W, 1%, 140V minimum	C1,C2	4n7, 210V minimum

Common to both:

R3,R4	475K	C3,C4	4n7
R5,R6,R7,R8	52K3	C5,C6	100n
R9	249K	C7,C8	1u
R10	475K	Q1,Q2	PNP. 2N3906 or equivalent
R11	523K	Q3,Q4	NPN. 2N3904 or equivalent
R12-R15	10K, 10%	D1-D4	Diode. 1N4148 or equivalent

DESIGN EQUATIONS:

For SELECT=5V
R1=R2, R5=R6, C1=C2, C5=C6
(R7 series C7)||R9 = (R8 series C8)||R10||R11
Since the requirement for SELECT=0V is
R7=R8 & C7=C8, thus R9 = R10||R11.
In Band Gain = R11/(R1+R5)
HP ω3dB = 1/(R1+R5)(C1 series C5)

For SELECT=0V
R3=R4, R7=R8, C3=C4, C7=C8
(R5 series C5)||R9 = (R6 series C6)||R10||R11
Since the requirement for SELECT=5V is
R5=R6 & C5=C6, thus R9 = R10||R11.
In Band Gain = R11/(R3+R7)
HP ω3dB = 1/(R3+R7)(C3 series C7)

Note that R5 and R7 need not be equal. R5 = R7 has been chosen so that the non-inverting gain is the same when SELECT=5V and 0V.

Figure 1 - Differential 2 Wire/Differential 4 Wire Select Circuit

Selecting between two Differential Inputs

When the SELECT signal in Figure 1 is at 5V, the TIP/RING input is selected. When SELECT is at 0V, the Rx+/Rx- input is selected. There are two methods to use the SELECT signal. One is to set SELECT to 5V when the phone is on hook, and 0V when the phone is off hook. Another is to set SELECT to 5V when FSK is expected, 0V when CAS is expected. The component values shown are for unity gain. When controlling SELECT via the second method it is possible to have different gains for FSK and CAS: the FSK gain via R1 R2, the CAS gain via R3 R4. If the FSK gain is to be greater than 0dB, R11 should be increased to set the gain while keeping the R1 and R5 values in Figure 1.

Figure 2 shows the equivalent circuit when SELECT is 5V. Transistors Q1 and Q2 are off and the TIP/RING input is selected. Q3 and Q4 are on and attenuate the Rx+ and Rx- inputs so that the left hand side of R7 and R8 can be treated as circuit ground. C7 and C8 are needed to AC couple the right hand side of R7 and R8 so that the op amp DC output is not affected. This circuit can be analyzed via superposition of the non-inverting gain for the TIP input and the inverting gain for the RING input. It is a high pass filter whose -3dB frequency is $1/2\pi(R1+R5)(C1 \text{ series } C5)$. For the selected component values it is 68Hz. When calculating the passband gain the capacitors can be replaced with short circuits.

Figure 3 shows the non-inverting gain configuration. The passband gain is:

$$\frac{V_{GS}}{V_1} = 1 + \frac{R11}{R10||R8||(R2+R6)}$$
$$= 1 + \frac{523K}{475K||52K3||(470K+52K3)} = 13.102393$$

and

$$\frac{V_1}{V_{TIP}} = \frac{R9||R7}{(R9||R7)+R1+R5}$$
$$= \frac{249K||52K3}{(249K||52K3)+470K+52K3} = \frac{1}{13.084206}$$

Therefore

$$V_{GS} = 13.102393V_1 = 13.102393\left(\frac{1}{13.084206}\right)V_{TIP}$$
$$= 1.0013900V_{TIP}$$

The inverting gain configuration is shown in Figure 4. The passband gain is

$$\frac{V_{GS}}{V_{RING}} = \frac{-R11}{R2+R6} = \frac{-523K}{470K+52K3} = -1.0013402$$

The differential gain is the sum of the non-inverting and inverting gains.

$$V_{GS} = 1.0013900V_{TIP} - 1.0013402V_{RING} = V_{TIP} - V_{RING}$$

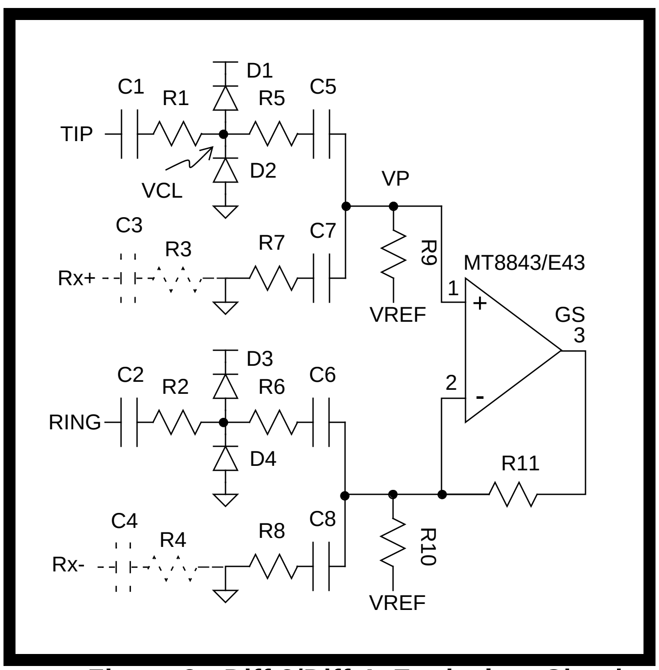


Figure 2 - Diff 2/Diff 4: Equivalent Circuit when SELECT=5V

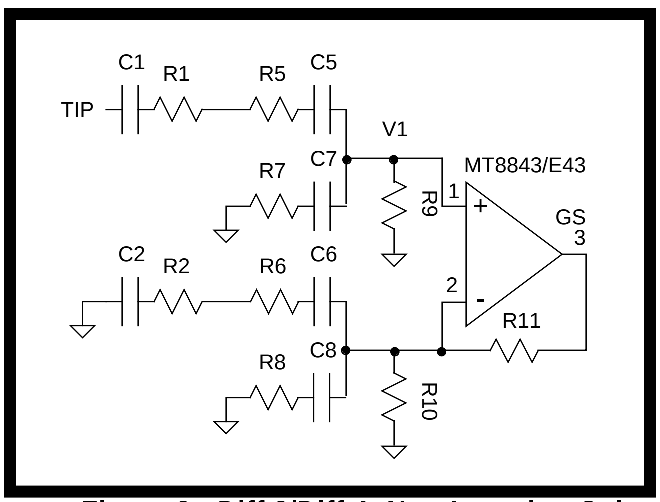


Figure 3 - Diff 2/Diff 4: Non-Inverting Gain when SELECT=5V

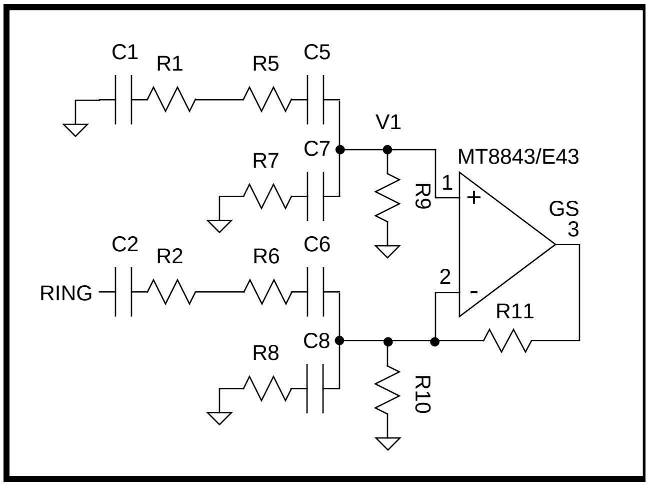


Figure 4 - Diff 2/Diff 4: Inverting Gain when SELECT=5V

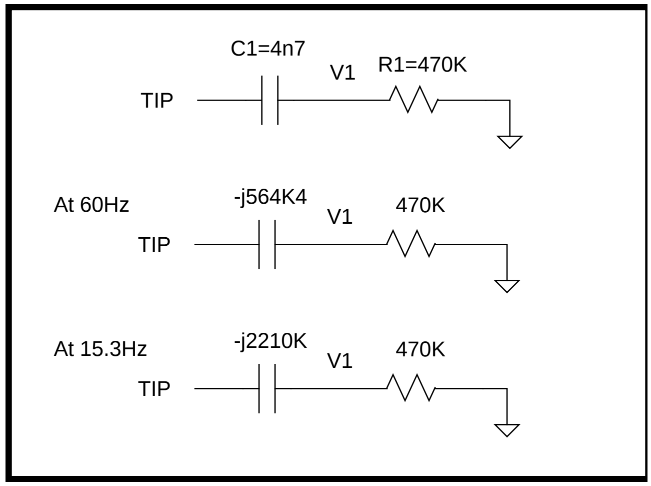


Figure 5 - Diff 2/Diff 4: Equivalent Circuit when TIP is Clamped

V_{GS} is not exactly 1.0013402(V_{TIP}-V_{RING}) because R10||R11 is not exactly equal to R9. By picking R9= 249K and R11=523K, R10 should be 475K28.

When SELECT is 0V, Q3 and Q4 are off and the Rx+/Rx- input is selected. The TIP and RING inputs are attenuated by the PNP transistors Q1 and Q2. The left hand side of R5 and R6 can be treated as 5V, and as AC ground for the gain analysis. C5 and C6 are required to AC couple the right hand side of R5 and R6 so that the DC output is not affected. The gain analysis is identical to the SELECT=5V case.

The TIP/RING input common mode range is limited by the clamping diodes D1 D2 to the left of R5, and D3 D4 to the left of R6. The diodes are required to limit the voltage at the op amp inputs during ringing and other high voltage TIP/RING events. In Figure 2 at Vdd=5V a large signal at TIP will cause VCL to be clipped when the peak to peak swing at VCL exceeds 5V. At 60Hz, VCL/VTIP is 1/8.20. Therefore the maximum TIP/RING common mode input is 8.20(2.5)=14.5Vrms.

Unlike TIP/RING, the Rx+/- input common mode range is limited only by the op amp common mode range because there are no clamping diodes. In Figure 2 when SELECT=0V VP/VRx+ is 1/16.95 at 60Hz. The op amp common mode range is 1V to Vdd-1V. Therefore at Vdd=5V the maximum common mode input is 1.5(16.95)=18.0Vrms.

Figure 5 shows the equivalent circuit when the diodes D1 D2 are clamping the TIP input. The situation is identical for the RING input. Figure 5 can be used to calculate the C1 C2 voltage ratings and the R1 R2 power ratings. There are two requirements to consider: 1KVrms 60Hz isolation, and ringing.

For the isolation requirement a 1KVrms 60Hz AC voltage is applied between TIP and Earth, RING and Earth. At 60Hz

$$\frac{V_1}{V_{TIP}} = 0.640(50.21°)$$
$$\frac{V_{C1}}{V_{TIP}} = 1-\frac{V_1}{V_{TIP}} = 0.768(-39.78°)$$

The voltage across C1 is 768Vrms, across R1 is 640Vrms. Therefore C1 and C2 should be rated for 768Vrms=1086Vpeak, R1 and R2 for 640^2/470K= 0.871Watt.

If isolation is handled via other means then C1 C2 and R1 R2 should be rated for ringing. The specification for the FCC Part 68 Type B ringer is 15.3 to 68.0Hz, 40 to 150Vrms. The impedance of C1 is greatest at 15.3Hz. Hence maximum voltage across C1 occurs at 15.3Hz. At 15.3Hz

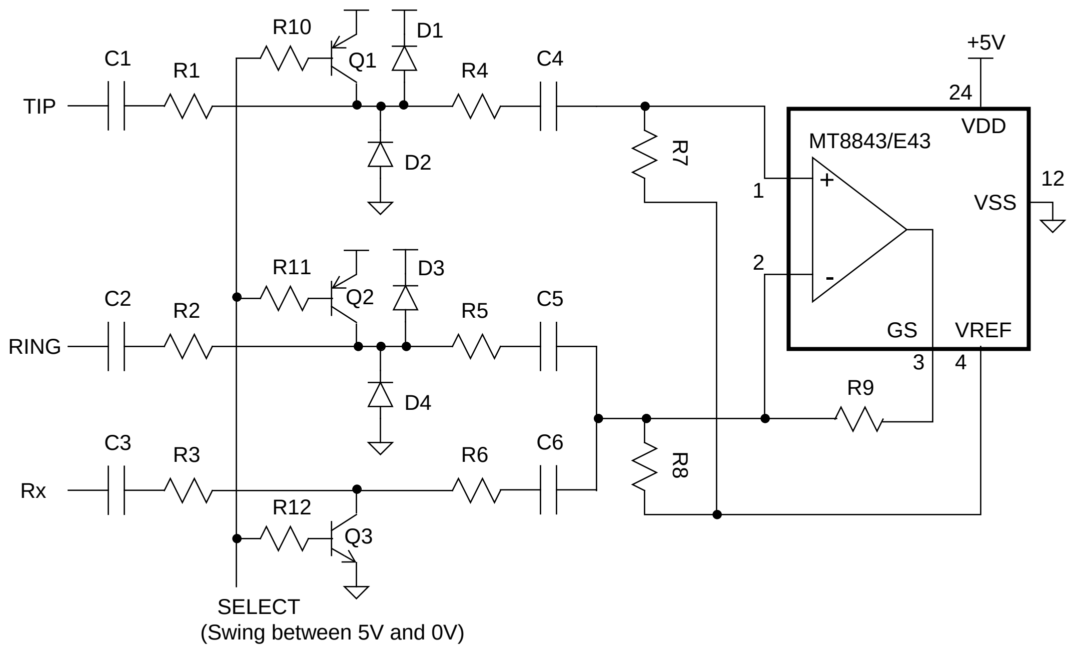
$$\frac{V_1}{V_{TIP}} = 0.208(77.99°)$$
$$\frac{V_{C1}}{V_{TIP}} = 1-\frac{V_1}{V_{TIP}} = 0.978(-12.01°)$$

Therefore C1 and C2 should be rated 150(0.978)= 147Vrms=208Vpeak. Maximum voltage across R1 occurs at 68Hz. At 68Hz, V_1/V_{TIP}=0.686(46.66°). Therefore maximum V_1 is 150(0.686)=103Vrms. R1 and R2 should be rated 103^2/470K=0.0226Watt.

The Figure 1 circuit is a high pass filter. The TIP/RING input corner frequency is determined by C1, C5 and R1, R5. For the selected component values it is 68Hz. It has been selected so that the op amp output will not saturate when a 1589mVrms 60Hz interfering tone is added to a 200mVrms FSK signal. This requirement is part of the TIA (Telecommunications Industry Association) "Type 1 Caller Identity Equipment Performance Requirements". Bellcore has indicated that it will incorporate the TIA requirements into its future documents. The MT8843/E43 will demodulate the FSK signal correctly in the presence of such an interfering 60Hz signal.

The Rx+/Rx- input corner frequency is determined by C3, C7, R3, R7. It is 65Hz because C7 is 1uF instead of the 0.1uF for C5. C7 has been chosen such that its capacitance deviation will not significantly affect the TIP/RING common mode attenuation. Among other things, good TIP/RING common mode attenuation requires impedance matching between (R7 series C7)||R9 and (R8 series C8)||R10||R11. At 60Hz 1uF is -j2K65. Hence the impedance of (R7 series C7) is dominated by R7. Small C7 variation will not severely affect the matching with (R8 series C8).

For good TIP/RING common mode attenuation C1 and C2 should be matched. Matching between C5 and C6 is less significant because the impedance (C1 series C5) is dominated by C1. This circuit has been simulated to provide 26dB common mode attenuation when C1 is 4n7-5% and C2 is 4n7+5%; 32dB when the deviations are reduced to -2.5% and +2.5%. In the simulation the resistors were at the nominal values, C7 was 1uF+5%, C8 was 1uF-5%.



Unless stated otherwise, resistors are 1%, 0.1Watt; capacitors are 5%, 6.3V.

For 1000Vrms, 60Hz isolation from Tip to Earth and Ring to Earth:

R1,R2	430K, 1W, 5%, 1KV (e.g. IRC Type GS-3)	C1,C2	4n7, 1124V minimum

For FCC Part 68 Type B Ringing:

R1,R2	432K, 0.1W, %, 140V minimum	C1,C2	4n7, 210V minimum

Common to both:

R3	340K	C3	4n7
R4,R5	34K0	C4,C5	100n
R6	121K	C6	1u
R7	53K6	Q1,Q2	PNP. 2N3906 or equivalent
R8	121K	Q3	NPN. 2N3904 or equivalent
R9	464K	D1-D4	Diode. 1N4148 or equivalent
R10,R11,R12	10K, 10%		

DESIGN EQUATIONS:

For SELECT=5V
In Band Gain = R9/(R1+R4)
HP ω3dB = 1/(R1+R4)(C1 series C4)

For SELECT=0V
In Band Gain = -R9/(R3+R6)
HP ω3dB = 1/(R3+R6)(C3 series C6)

R1=R2, R4=R5, C1=C2, C4=C5
R7 = (R6 series C6)||R10||R11. Approximated by R7=R6||R10||R11.

Figure 6 - Differential 2 Wire/Single Ended 4 Wire Select Circuit

For the Rx+/Rx- input there is less need for common mode attenuation because it is unlikely that Rx+/Rx- has any significant common mode signal. If good common mode attenuation is required C5 should match C6 and C3 should match C4.

Selecting between a Differential and a Single Ended Input

In Figure 6 when SELECT is 5V the TIP/RING input is selected, and when SELECT is 0V the single ended Rx input is selected. There are two methods to use the SELECT signal. One is to set SELECT to 5V when the phone is on hook for FSK, 0V when the phone is off hook for FSK and CAS. Another is to set SELECT to 5V when FSK is expected, 0V when CAS is expected. The component values are for unity gain. The second method allows different gains for FSK and CAS: FSK gain via R1 and R2, CAS gain via R3. If the FSK gain is to be greater than 0dB, R9 should be used to set the gain while keeping the R1 and R4 values in Figure 6.

Figure 7 shows the equivalent circuit when SELECT is 5V. Transistors Q1 and Q2 are off and the TIP/RING input is selected. Q3 is on and attenuates the Rx input so that the left hand side of R6 can be treated as circuit ground. C6 is needed to AC couple the right hand side of R6 so that the op amp DC output is not affected. This circuit can be analyzed via superposition of the non-inverting gain for the TIP input and the inverting gain for the RING input. It is a high pass filter. The -3dB frequency is $1/2\pi(R1+R4)(C1 \text{ series } C4)$. For the component values in Figure 6 it is 76Hz. When calculating the passband gain the capacitors can be replaced with short circuits.

Figure 8 shows the non-inverting gain configuration. The passband gain is:

$$\frac{V_{GS}}{V_1} = 1 + \frac{R9}{R8||R6||(R2+R5)}$$
$$= 1 + \frac{464K}{121K||121K||(430K+34K)} = 9.669421$$

and

$$\frac{V_1}{V_{TIP}} = \frac{R7}{R7+R1+R4}$$
$$= \frac{53K6}{53K6+430K+34K} = \frac{1}{9.656716}$$

Therefore

$$V_{GS} = 9.669421V_1 = 9.669421\left(\frac{1}{9.656716}\right)V_{TIP}$$
$$= 1.001316V_{TIP}$$

The inverting gain configuration is shown in Figure 9. The passband gain is

$$\frac{V_{GS}}{V_{RING}} = \frac{-R9}{R2+R5} = \frac{-464K}{430K+34K} = -1.000000$$

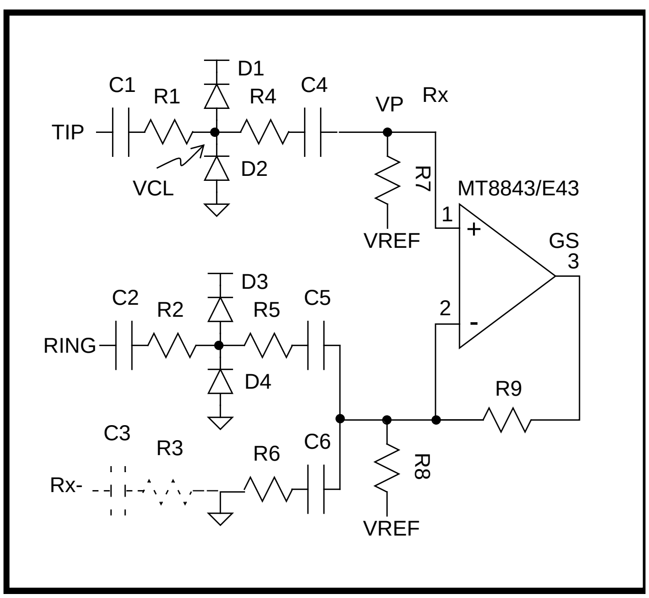


Figure 7 - Diff 2/Single 4: Equivalent Circuit when SELECT=5V

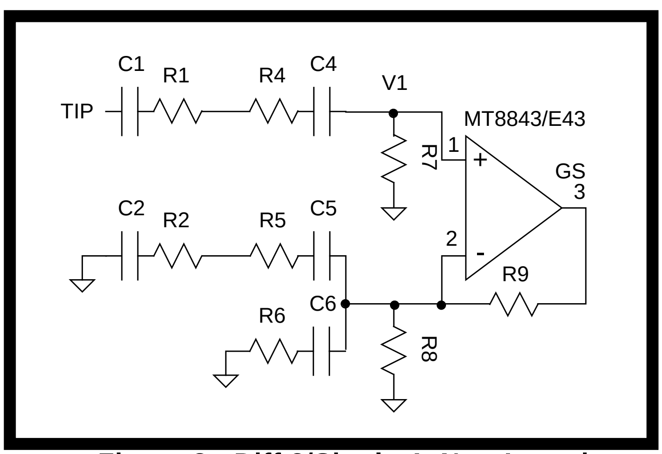


Figure 8 - Diff 2/Single 4: Non-Inverting Gain when SELECT=5V

The differential gain is the sum of the non-inverting and inverting gains.

$$V_{GS} = 1.001316V_{TIP} - 1.000000V_{RING} = V_{TIP} - V_{RING}$$

V_{GS} is not exactly 1.000000(V_{TIP}-V_{RING}) because R6||R8||R9 is not exactly equal to R7. By picking R7= 53K6 and R9=464K, R6 and R8 should be 121K201.

When SELECT is 0V, Q3 is off and the Rx input is selected. The TIP and RING inputs are attenuated by the PNP transistors Q1 and Q2. The left hand side of R4 and R5 can be treated as 5V, and as AC ground for the gain analysis. C4 and C5 are needed to AC couple the right hand side of R4 and R5 so that the DC output of the op amp is not affected.

The equivalent circuit is shown in Figure 10. It is a high pass filter. The -3dB frequency is 1/2π(R3+R6)(C3 series C6). For the component values in Figure 6 it is 74Hz. The passband gain is

$$\frac{V_{GS}}{V_{RING}} = \frac{-R9}{R3 + R6} = \frac{-464K}{340K + 121K} = -1.006508$$

The TIP/RING input common mode range is limited by the clamping diodes D1 D2 to the left of R4, and D3 D4 to the left of R5. The diodes are required to limit the voltage at the op amp inputs during ringing and other high voltage TIP/RING events. In Figure 7 at Vdd=5V a large signal at TIP will cause VCL to be clipped when the peak to peak swing at VCL exceeds 5V. At 60Hz, VCL/VTIP is 1/8.62. Therefore the maximum TIP/RING common mode input is 8.62(2.5)=15.2Vrms.

Figure 11 shows the equivalent circuit when the diodes D1 D2 are clamping the TIP input. The situation is identical for the RING input. Figure 11 can be used to calculate the C1 C2 voltage ratings and the R1 R2 power ratings. There are two requirements to consider: 1KVrms 60Hz isolation, and ringing.

For the isolation requirement a 1KVrms 60Hz AC voltage is applied between TIP and Earth, RING and Earth. At 60Hz

$$\frac{V_1}{V_{TIP}} = 0.606(52.70°)$$

$$\frac{V_{C1}}{V_{TIP}} = 1 - \frac{V_1}{V_{TIP}} = 0.795(-37.31°)$$

The voltage across C1 is 795Vrms, across R1 is 606Vrms. Therefore C1 and C2 should be rated for 795Vrms=1124Vpeak, R1 and R2 for 606^2/430K= 0.854Watt.

If isolation is handled via other means then C1 C2 and R1 R2 should be rated for ringing. The specification for the FCC Part 68 Type B ringer is 15.3 to 68.0Hz, 40 to 150Vrms. The impedance of C1 is greatest at 15.3Hz. Hence maximum voltage across C1 occurs at 15.3Hz. At 15.3Hz

$$\frac{V_1}{V_{TIP}} = 0.191(79.00°)$$

$$\frac{V_{C1}}{V_{TIP}} = 1 - \frac{V_1}{V_{TIP}} = 0.982(-11.00°)$$

Therefore C1 and C2 should be rated 150(0.982)= 147Vrms=208Vpeak. Maximum voltage across R1 occurs at 68Hz. At 68Hz, V_1/V_{TIP}=0.654(49.19°). Therefore maximum V_1 is 150(0.654)=98Vrms. R1 and R2 should be rated 98^2/430K=0.0223Watt.

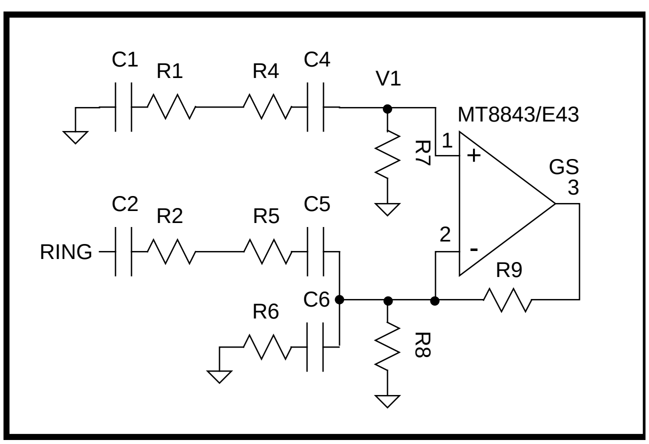


Figure 9 - Diff 2/Single 4: Inverting Gain when SELECT=5V

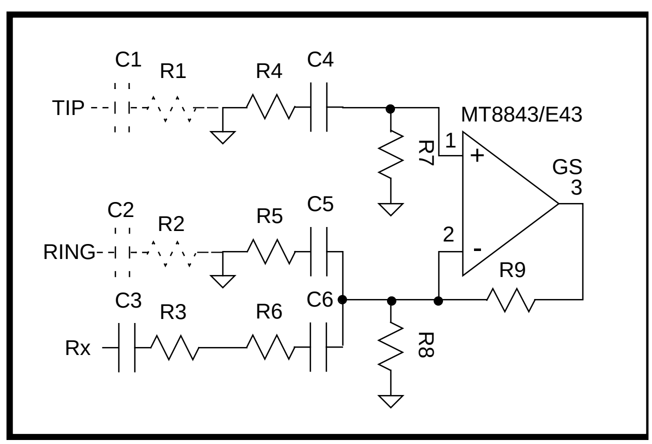


Figure 10 - Diff 2/Single 4: Inverting Gain when SELECT=0V

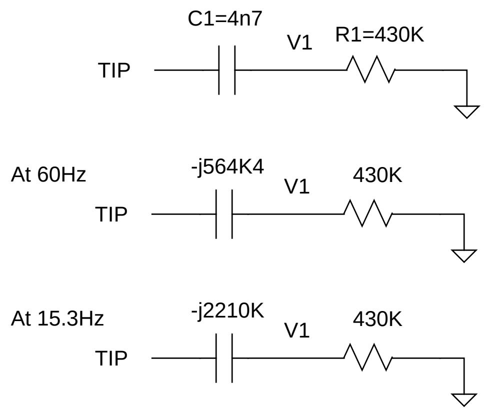


Figure 11 - Diff 2/Single 4: Equivalent Circuit when TIP is Clamped

In the SELECT=5V equivalent circuit in Figure 7, for perfect TIP/RING common mode attenuation R1+R4 should equal R2+R5, (C1 series C4) should equal (C2 series C5), and R7 should equal (R6 series C6)||R8||R9. The R7 requirement is not possible. The solution is to make C6 large so that the impedance (R6 series C6) is dominated by R6. At 60Hz, C6 at 1uF is -j2K65. R6 is 121K so the series impedance is 121K(-1.25°). The impedance (R6 series C6)||R8||R9 is 53K5(-0.55°) is a close match for R7=53K6.

The TIP/RING input high pass corner frequency is determined by C1, C4 and R1, R4. For the selected component values it is 76Hz. It has been selected so that the op amp output will not saturate when a 1589mVrms 60Hz interfering tone is added to a 200mVrms FSK signal. This requirement is part of the TIA (Telecommunications Industry Association) "Type 1 Caller Identity Equipment Performance Requirements". Bellcore has indicated that it will incorporate the TIA requirements into its future documents. The MT8843/E43 will demodulate the FSK signal correctly in the presence of such an interfering 60Hz signal. The Rx input corner frequency is determined by C3, C6, R3, R6. It is 74Hz.

For good TIP/RING common mode attenuation C1 and C2 should be matched. Matching between C4 and C5 is less significant because the impedance (C1 series C4) is dominated by C1. This circuit has been simulated to provide 26dB common mode attenuation when C1 is 4n7-5% and C2 is 4n7+5%, and 31dB when the deviations are reduced to -2.5% and +2.5%. In the simulation the resistors values were nominal. A C4+5%, C5-5% mismatch reduces the common mode attenuation by 0.4dB.

Afterword

Two circuits have been presented to select between Tip/Ring and the hybrid receive pair. The circuits can also be used to assign different gains for FSK and CAS. In the differential receive pair case the bill of material overhead is 4 resistors (R12-15), 4 capacitors (C5-8) and 4 transistors. In the single ended receive pair case the overhead is 3 resistors (R10-12), 3 capacitors (C4-6) and 3 transistors.

The Tip/Ring 60Hz common mode range can be improved by increasing the high pass corner frequency. For example, in the differential receive pair case (Figure 1) if C1=C2=3n3 the corner frequency will be 95Hz, the common mode range will be 17.9Vrms versus 14.5Vrms for when C1=4n7. The trade-off is that a higher capacitor voltage rating will be required to meet 1KVrms isolation.