UniSLIC14 and the Texas Instruments TCM38C17 Quad Combo

Application Note | September 2000 | AN9903.1

Authors: Don LaFontaine, Chris Ludeman

Reference Design using the UniSLIC14 and the Texas Instruments TCM38C17 Quad Combo

The purpose of this application note is to provide a reference design for the UniSLIC14 and Texas Instruments TCM38C17 Quad Combo.

The network requirements of many countries require the analog subscriber line circuit (SLIC) to terminate the subscriber line with an impedance for voiceband frequencies which is complex, rather than resistive (e.g. 600Ω). The UniSLIC14 accomplishes this impedance matching with a single network connected to the Z_T pin.

The TCM38C17 Quad Combo has a programmable receive output amplifier to adjust the output gain into the SLIC. The output amplifier gain is programmed with two simple resistors. Transhybrid balance is achieved via the TCM38C17 GSX amplifier.

Discussed in this application note are the following:

- 2-wire 600Ω impedance matching.
- Receive gain (4-wire to 2-wire) and transmit gain (2-wire to 4-wire) calculations.
- Transhybrid balance calculations.
- Reference design for 600Ω 2-wire load.
- Reference design for China complex 2-wire load.

Impedance Matching

Impedance matching of the UniSLIC14 to the subscriber load is important for optimization of 2 wire return loss, which in turn cuts down on echoes in the end to end voice communication path. It is also important for maintaining voice signal levels on long loops. Impedance matching of the UniSLIC14 is accomplished by making the SLIC's impedance (Z_{SLIC}, Figure 1) equal to the desired terminating impedance Z_0, minus the value of the protection resistors ($Z_{TR} = Z_O$). The formula to calculate the proper Z_T for matching the 2-wire impedance is shown in Equation 1.

$$Z_T = 200 \bullet (Z_{TR} - 2R_P) \qquad \text{(EQ. 1)}$$

Equation 1 can be used to match the impedance of the SLIC and the protection resistors (Z_{TR}) to any known line impedance (Z_O). Figure 1 shows the calculations of Z_T to match a resistive and 2 complex loads.

EXAMPLE 1:

Calculate Z_T to make Z_{TR} = 600Ω in series with 2.16µF. R_P = 30Ω.

$$Z_T = 200\left(600 + \frac{1}{j\omega 2.16X10^{-6}} - (2)(30)\right) \qquad \text{(EQ. 2)}$$

Z_T = 108kΩ in series with 0.0108µF.

Note: Some impedance models, with a series capacitor, will cause the op-amp feedback to behave as an open circuit DC. A resistor with a value of about 10 times the reactance of the Z_T capacitor (2.16µF/200 = 10.8nF) at the low frequency of interest (200Hz for example) can be placed in parallel with the capacitor in order to solve the problem (736kΩ for a 10.8nF capacitor).

EXAMPLE 2:

Calculate Z_T to make Z_{TR} = 200 + 680//0.1µF R_P = 30Ω.

$$Z_T = 200\left(200 + \frac{680}{1 + j\omega 680(0.1)X10^{-6}} - (2)(30)\right) \qquad \text{(EQ. 3)}$$

Z_T = 28kΩ in series with the parallel combination of 136kΩ and 500pF.

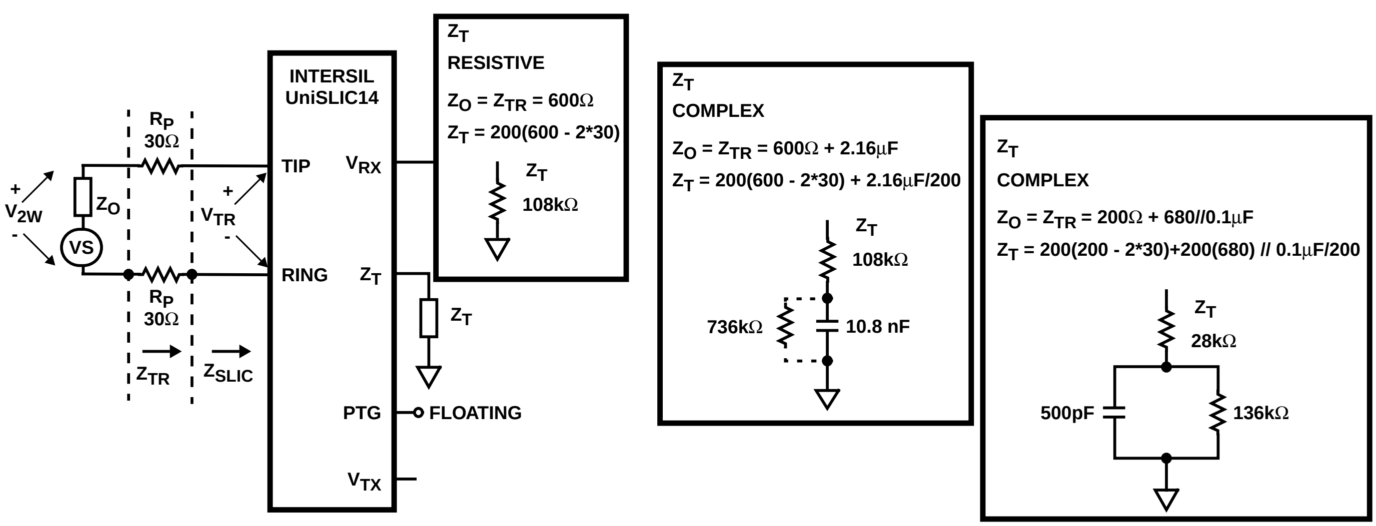

FIGURE 1. IMPEDANCE MATCHING

SLIC in the Active Mode

Figure 2 shows a simplified AC transmission model of the UniSLIC14 and the connection of the TCM38C17 to the SLIC. Circuit analysis of the UniSLIC14 yields the following design equations:

$$V_A = I_M \times 2R_S \times \frac{1}{80k} \times 200(Z_{TR} - 2R_P) \times 5 \qquad \text{(EQ. 4)}$$

$$V_A = \frac{I_M}{2}(Z_{TR} - 2R_P) \qquad \text{(EQ. 5)}$$

Node Equation at UniSLIC14 V_{RX} input

$$\frac{V_{RX}}{500k} - \frac{V_A}{500k} = I_X \qquad \text{(EQ. 6)}$$

Substitute Equation 5 into Equation 6

$$I_X = \frac{V_{RX}}{500k} - \frac{I_M(Z_{TR} - 2R_P)}{1000k} \qquad \text{(EQ. 7)}$$

Loop Equation at UniSLIC14 feed amplifier and load

$$I_X 500k - V_{TR} + I_X 500k = 0 \qquad \text{(EQ. 8)}$$

Substitute Equation 7 into Equation 8

$$V_{TR} = 2V_{RX} - I_M(Z_{TR} - 2R_P) \qquad \text{(EQ. 9)}$$

Loop Equation at Tip/Ring interface

$$V_{2W} - I_M 2R_P + V_{TR} = 0 \qquad \text{(EQ. 10)}$$

Substitute Equation 9 into Equation 10

$$V_{2W} = I_M Z_{TR} - 2V_{RX} \qquad \text{(EQ. 11)}$$

Substituting $-V_{2W}/Z_L$ into Equation 11 for I_M and rearranging to solve for V_{2W} results in Equation 12.

$${}_{2W}\left(1 + \frac{Z_{TR}}{Z_L}\right) = -2V_{RX} \qquad \text{(EQ. 12)}$$

where:

V_{RX} = The input voltage at the V_{RX} pin.

V_A = An internal node voltage that is a function of the loop current detector and the impedance matching networks.

I_X = Internal current in the SLIC that is the difference between the input receive current and the feedback current.

I_M = The AC metallic current.

R_P = A protection resistor (typical 30Ω).

Z_T = An external resistor/network for matching the line impedance.

V_{TR} = The tip to ring voltage at the output pins of the SLIC.

V_{2W} = The tip to ring voltage including the voltage across the protection resistors.

Z_O = The line impedance.

Z_{TR} = The input impedance of the SLIC including protection resistors.

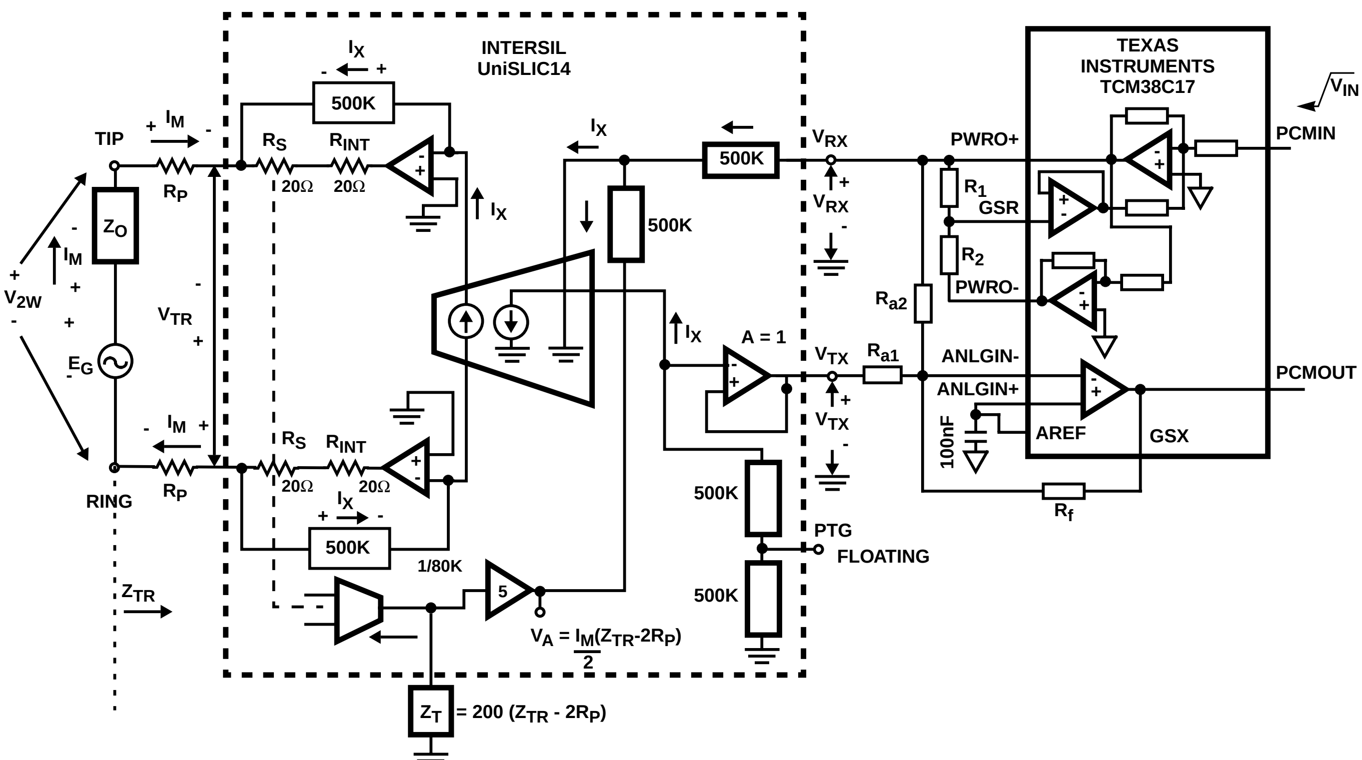

FIGURE 2. UniSLIC14 SIMPLIFIED AC TRANSMISSION CIRCUIT AND TCM38C17

Receive Gain (V_{IN} to V_{2W})

4-wire to 2-wire gain is equal to the V_{2W} divided by the input voltage V_{IN}, reference Figure 3. The gain through the TCM38C17 is programmed to be 1.0 using Equation 13, where $V_{IN} = V_{PCMIN} = V_{PWRO+} = V_{RX}$.

$$G_{(PCMIN-PWRO+)} = \frac{R_1 + R_2}{4\left(R_2 + \frac{R_1}{4}\right)} \qquad \text{(EQ. 13)}$$

The input and output gain adjustments are discussed in detail in PCM CODEC / Filter Combo Family: Device Design-in and Application Data [1]. The maximum output (Gain =1) can be obtained by maximizing R_1 and minimizing R_2 (Figure 2). This can be done by letting R_1= infinity and R_2 = 0, as shown in Figure 3.

The receive gain is calculated using Equation 12 and the relationship $Z_T = 200(Z_{TR}\text{-}2R_P)$.

Equation 14 expresses the receive gain (V_{IN} to V_{2W}) in terms of network impedances.

$$G_{4\text{-}2} = \frac{V_{2W}}{V_{IN}} = -2\frac{Z_O}{Z_O + Z_{TR}} = -2\frac{Z_O}{Z_O + \left(\frac{Z_T}{200} + 2R_P\right)} \qquad \text{(EQ. 14)}$$

Notice that the phase of the 4-wire to 2-wire signal is 180^o out of phase with the input signal.

Transmit Gain Across UniSLIC14 (E_G to V_{TX})

The 2-wire to 4-wire gain is equal to V_{TX}/E_G with V_{RX} = 0, reference Figure 2.

Loop Equation (EQ. 15)

$$-E_G + Z_L I_M + 2R_P I_M - V_{TR} = 0$$

From Equation 9 with V_{RX} = 0

$$V_{TR} = -I_M(Z_{TR} - 2R_P) \qquad \text{(EQ. 16)}$$

Substituting Equation 16 into Equation 15 and simplifying.

$$E_G = I_M(Z_L + Z_{TR}) \qquad \text{(EQ. 17)}$$

By design, $V_{TX} = -V_{TR}$, therefore,

$$G_{2\text{-}4} = \frac{V_{TX}}{E_G} = \frac{I_M(Z_{TR} - 2R_P)}{I_M(Z_L + Z_{TR})} = \frac{(Z_{TR} - 2R_P)}{(Z_L + Z_{TR})} \qquad \text{(EQ. 18)}$$

A more useful form of the equation is rewritten in terms of V_{TX}/V_{2W}. A voltage divider equation is written to convert from E_G to V_{2W} as shown in Equation 19.

$$V_{2W} = \left(\frac{Z_{TR}}{Z_{TR} + Z_L}\right)E_G \qquad \text{(EQ. 19)}$$

Rearranging Equation 19 in terms of E_G, and substituting into Equation 18 results in an equation for 2-wire to 4-wire gain that's a function of the synthesized input impedance of the SLIC and the protection resistors (Z_{TR}).

$$G_{2\text{-}4} = \frac{V_{TX}}{V_{2W}} = \frac{Z_{TR} - 2R_P}{Z_{TR}} = \frac{Z_0 - 2R_P}{Z_0} \qquad \text{(EQ. 20)}$$

Notice that the phase of the 2-wire to 4-wire signal is in phase with the input signal and that the gain will always be less than one because of the protection resistors.

Transmit Gain Across the System (V_{2W} to V_{PCMOUT})

2-wire to 4-wire gain is equal to the V_{PCMOUT} voltage divided by the 2-wire voltage V_{2W}, reference Figure 3.

$$G_{2-4} = \frac{V_{PCMOUT}}{V_{2W}} \qquad \text{(EQ. 21)}$$

V_{PCMOUT} is only a function of V_{TX} and the feedback resistors R_{a1} and R_f Equation 22. This is because V_{IN} is considered ground for this analysis, thereby effectively grounding the V_{PWRO+} output.

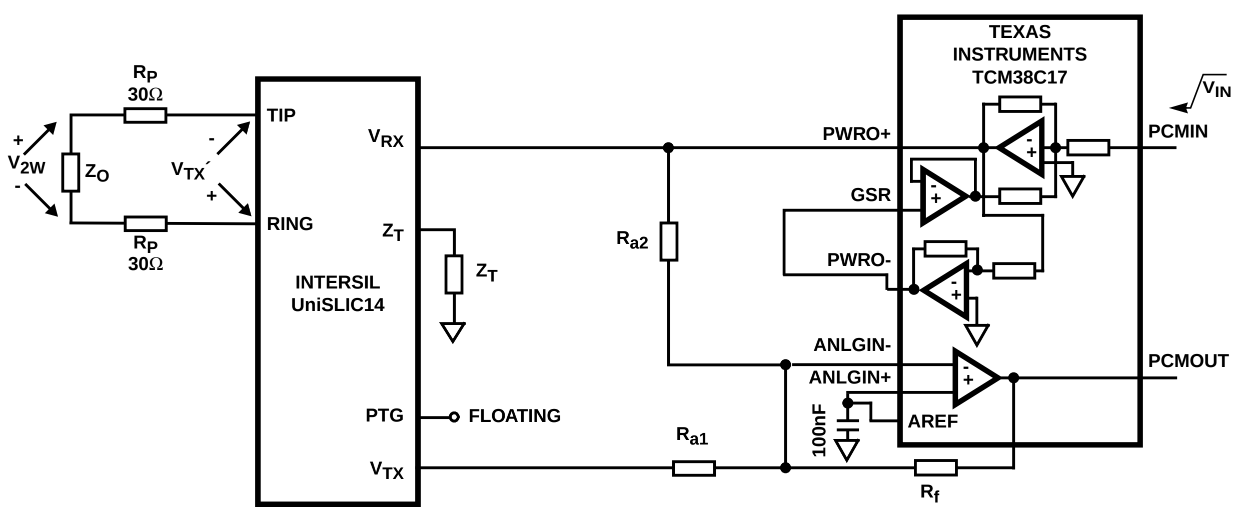

FIGURE 3. RECEIVE GAIN G(4-2), TRANSMIT GAIN (2-4) AND TRANSHYBRID BALANCE

$$V_{PCMOUT} = -V_{TX}\frac{R_f}{R_{a1}} \quad \text{(EQ. 22)}$$

An equation for the system transmit gain is achieved by substituting Equation 20 into Equation 22.

$$G_{2-4} = \frac{V_{PCMOUT}}{V_{2W}} = \frac{(Z_0 - 2R_P)}{Z_0}\frac{R_f}{R_{a1}} \quad \text{(EQ. 23)}$$

To achieve a Transmit Gain of one (V_{PCMOUT}/ V_{2W}), make $R_f = Z_O$ and $R_a = (Z_0 - 2R_P)$. Actual values of R_{a1} and R_f were multiplied by 100 to reduce loading effects on the GSX opamp.

Transhybrid Balance G(4-4)

Transhybrid balance is a measure of how well the input signal is canceled (that being received by the SLIC) from the transmit signal (that being transmitted from the SLIC to the CODEC). Without this function, voice communication would be difficult because of the echo.

The signals at V_{PWRO+} and V_{TX} (Figure 3) are opposite in phase. Transhybrid balance is achieved by summing two signals that are equal in magnitude and opposite in phase into the GSX amplifier.

Transhybrid balance is achieved by summing the PWRO+ signal with the output signal from the UniSLIC14 when proper gain adjustments are made to match V_{PWRO+} and V_{TX} magnitudes.

For discussion purpose, the GSX amplifier is redrawn with the external resistors in Figure 4.

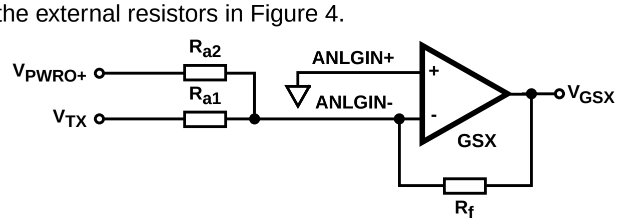

FIGURE 4. TRANSHYBRID BALANCE CIRCUIT

The gain through the GSX amplifier from V_{PWRO+} is set by resistors R_{a2} and R_{fr}.The gain through the GSX amplifier from V_{TX} is set by resistors R_{a1} and R_f.

Transhybrid balance is achieved by adjusting the magnitude from both V_{PWRO+} and V_{TX} so their equal to each other.

Reference Design of the UniSLIC14 and the TCM38C17 With a 600Ω Load

The design criteria is as follows:

- 4-wire to 2-wire gain (VP_{CMIN} to V_{2W}) equal 0dB
- 2-wire to 4-wire gain (V_{2W} to VP_{CMOUT}) equal 0dB
- Two Wire Return Loss greater than -30dB (200Hz to 4kHz)
- Rp = 30Ω

Figure 5 gives the reference design using the Intersil UniSLIC14 and the Texas Instruments TCM38C17 Quad Combo. Also shown in Figure 5 are the voltage levels at specific points in the circuit.

Impedance Matching

The 2-wire impedance is matched to the line impedance Z_0 using Equation 1, repeated here in Equation 24.

$$Z_T = 200 \bullet (Z_{TR} - 2R_P) \quad \text{(EQ. 24)}$$

For a line impedance of 600Ω, Z_T equals:

$$Z_T = 200 \bullet (600 - 60) = 108k\Omega \quad \text{(EQ. 25)}$$

The closest standard value for Z_T is 107kΩ.

Transhybrid Balance (Z_L = 600Ω)

The internal GSX amplifier of the TCM38C17 is used to perform the transhybrid balance function. Transhybrid balance is achieved by summing two signals that are equal in magnitude and opposite in phase into the GSX amplifier. From Equation 23, repeated here in Equation 26, a Transmit Gain (V_{PCMOUT}/ V_{2W}) of one is achieved if we make $R_f = Z_O$ and $R_{a1} = (Z_0 - 2R_P)$.

$$V_{PCMOUT} = \frac{V_{2W}(Z_0 - 2R_P)}{Z_0}\frac{R_f}{R_{a1}} \quad \text{(EQ. 26)}$$

$$R_f = Z_0 = 600(100) = 60k\Omega \quad \text{(EQ. 27)}$$

$$R_{a1} = (Z_0 - 2R_P) = (600 - 60)(100) = 54k\Omega \quad \text{(EQ. 28)}$$

Actual values of R_{a1} and R_f were multiplied by 100 to reduce loading effects on the GSX op-amp.

Closest standard value for R_f is 60.4kΩ
Closest standard value for R_{a1} is 53.6kΩ

The TCM38C17 receive gain is programmed to 1.0 by maximizing R_1 and minimizing R_2 resistor values (Figure 2).

The gain from PWRO+/V_{RX} through the SLIC at V_{TX} is 1.1 (Eq. 31 in the Intersil UniSLIC14 data sheet).

To achieve transhybrid balance from the PWRO+ pin to PCMOUT set $R_{a2} = R_{a1}$ x 0.9.

$$R_{a2} = (53.6K)(0.9) = 48.24K\Omega \quad \text{(EQ. 29)}$$

Closest standard value for R_{a2} = 48.6kΩ.

Specific Implementation for China

The design criteria for a China specific solution are as follows:

- Desired line circuit impedance is 200 + 680//0.1µF
- Receive gain (V_{2W}/V_{PCMIN}) is -3.5dB
- Transmit gain (V_{PCMOUT}/V_{2W}) is 0dB
- 0dBm0 is defined as 1mW into the complex impedance at 1020Hz
- R_p = 30Ω

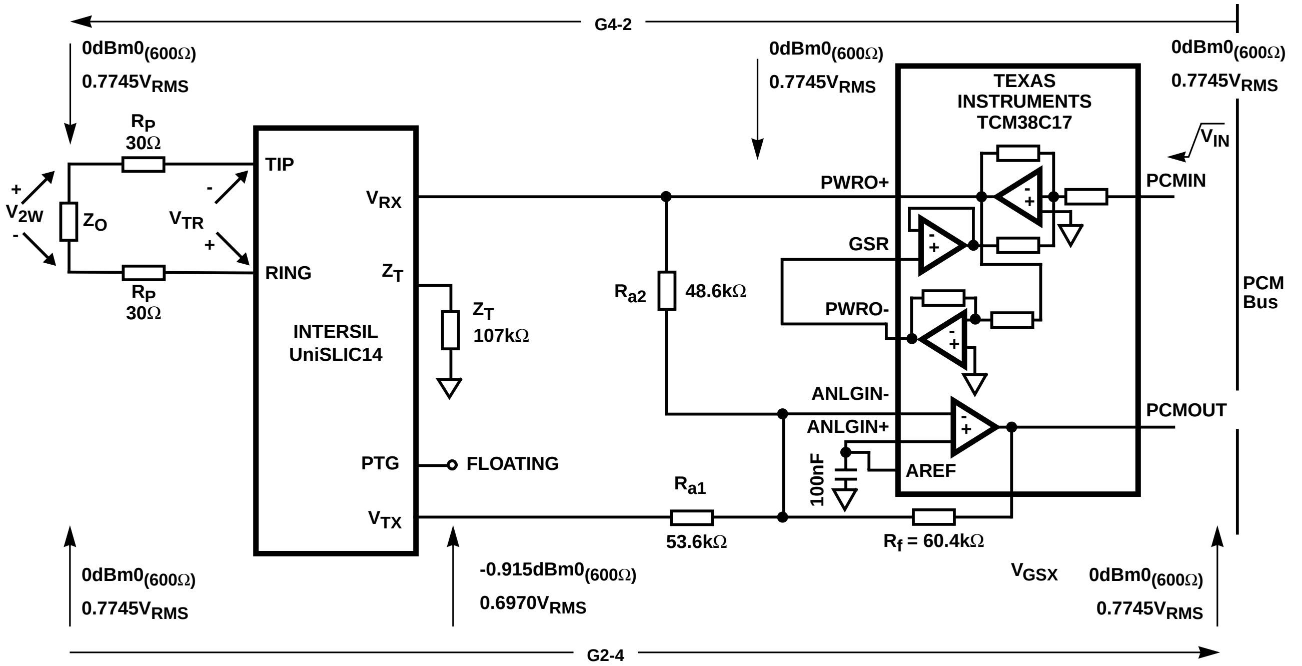

FIGURE 5. REFERENCE DESIGN OF THE UniSLIC14 AND THE TCM38C17 WITH A 600Ω LOAD IMPEDANCE

Figure 6 gives the reference design using the Intersil UniSLIC14 and the Texas Instruments TCM38C17 Quad Combo. Also shown in Figure 6 are the voltage levels at specific points in the circuit. These voltages will be used to adjust the gains of the network.

Adjustment to Get -3.5dBm0 at the Load Referenced to 600Ω

The voltage equivalent to 0dBm0 into 811Ω ($0dBm0_{(811\Omega)}$) is calculated using Equation 30 (811Ω is the impedance of complex China load at 1020Hz).

$$0dBm_{(811\Omega)} = 10\log\frac{V^2}{811(0.001)} = 0.90055V_{RMS} \quad \text{(EQ. 30)}$$

The gain referenced back to $0dBm0_{(600\Omega)}$ is equal to:

$$GAIN = 20\log\frac{0.90055V_{RMS}}{0.7745V_{RMS}} = 1.309dB \quad \text{(EQ. 31)}$$

The adjustment to get -3.5dBm0 at the load referenced to 600Ω is:

$$\text{Adjustment} = -3.5dBm0 + 1.309dBm0 = -2.19dB \quad \text{(EQ. 32)}$$

The voltage at the load (referenced to 600Ω) is given in Equation 33:

$$-2.19dBm_{(600\Omega)} = 10\log\frac{V^2}{600(0.001)} = 0.60196V_{RMS} \quad \text{(EQ. 33)}$$

Impedance Matching

The 2-wire impedance is matched to the line impedance Z_0 using Equation 1, repeated here in Equation 34.

$$Z_T = 200 \bullet (Z_{TR} - 2R_P) \quad \text{(EQ. 34)}$$

For a line impedance of 200 + 680//0.1µF, Z_T equals:

$$Z_T = 200 \bullet \left(200 + \frac{680}{1 + j\omega 680(0.1)X10^{-6}} - (2)(30)\right) \quad \text{(EQ. 35)}$$

$$Z_T = 200 \bullet (140\Omega) + \left[200 \bullet 680\Omega \,\|\, \frac{0.1\mu F}{200}\right] \quad \text{(EQ. 36)}$$

Z_T = 28kΩ in series with the parallel combination of 136kΩ (closest standard value for is 137kΩ and 500pF (closest standard value for is 470pF).

To achieve a 4-wire to 2-wire gain (V_{PCMIN} to V_{2W}) that is equivalent to 0dBm(600Ω) at the complex load, the gain through the TCM38C17 (V_{PCMIN} to V_{PWRO+}) must equal -2.19dBm (0.60196V_{RMS}). The gain through the TCM38C17 will then equal -2.19dBm (0.60196V_{RMS}) divided by the input voltage 0dBm (0.7745V_{RMS}). This gain is equal to 0.777.

The gain through the TCM38C17 (V_{PCMIN} to V_{PWRO+}) is given in Equation 13 and repeated here in Equation 37.

$$G_{(PCMIN-PWRO)} = \frac{R_1 + R_2}{4\left(R_2 + \frac{R_1}{4}\right)} \quad \text{(EQ. 37)}$$

Setting the gain equal to 0.777 we can now determine the value of the gain setting resistors R_1 and R_2. Selecting the value of R_1 to be 49.9kΩ, R_2 is calculated to 5.27kΩ. (Note: the value of R_1 + R_2 should be greater than 10kΩ but less than 100kΩ.)

$$0.777 = \frac{R_1 + R_2}{4\left(R_2 + \frac{R_1}{4}\right)} \quad \text{(EQ. 38)}$$

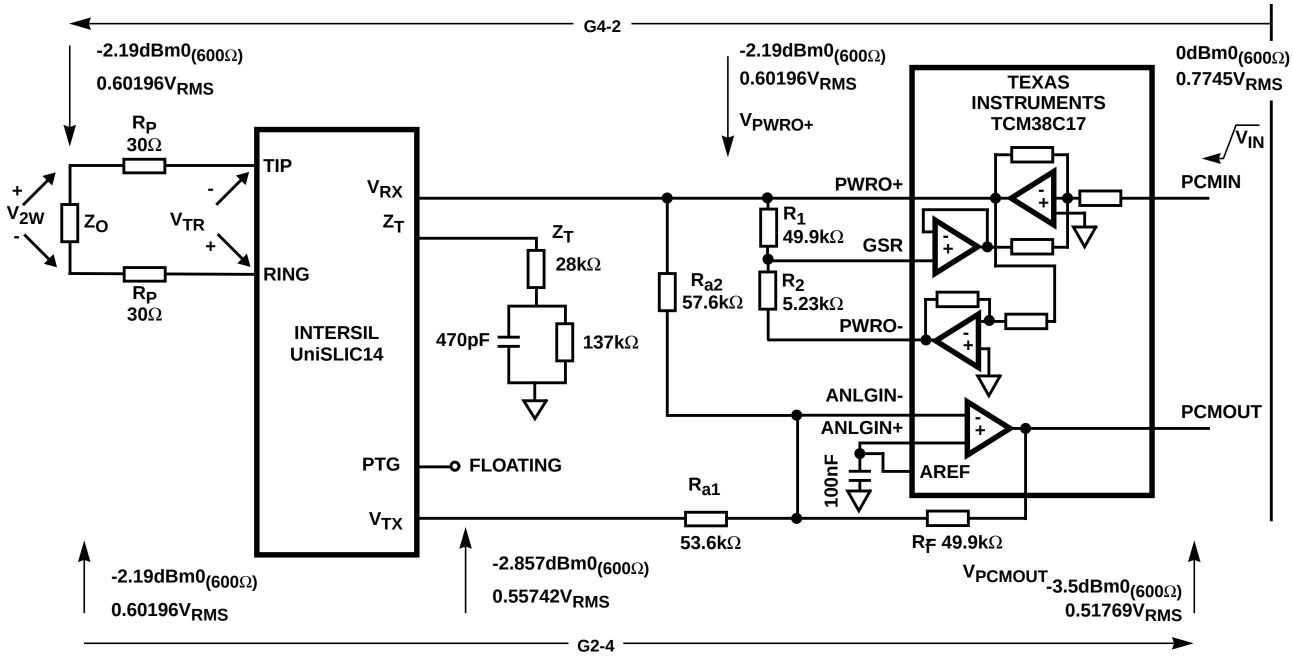

FIGURE 6. REFERENCE DESIGN OF THE UniSLIC14 AND THE TCM38C17 WITH CHINA COMPLEX LOAD IMPEDANCE

$$R_2 = R_1\left(\frac{0.222}{2.108}\right) = 49.9\text{k}\Omega(0.105) = 5.27\text{k}\Omega \quad \text{(EQ. 39)}$$

The closest standard value for R_2 is 5.23kΩ.

Transhybrid Balance (Z_L= 200 + 680//0.1μF)

The internal GSX amplifier of the TCM38C17 is used to perform the transhybrid balance function. The voltage at V_{TX} is equal to V_{PWRO+} times the 2-wire to 4-wire gain of the SLIC, as the gain from V_{RX} to V_{2W} = 1.0.

The 2-wire to 4-wire gain is calculated using Equation 20, repeated here in Equation 40.

$$G_{2\text{-}4} = \frac{V_{TX}}{V_{2W}} = \frac{Z_0 - 2R_P}{Z_0} \quad \text{(EQ. 40)}$$

Z_O for the China complex load at 1020Hz is equal to 811Ω.

$$G_{2\text{-}4} = \frac{811\Omega - 60\Omega}{811\Omega} = 0.92601 \quad \text{(EQ. 41)}$$

The voltage at V_{TX} is equal to V_{2W} times the 2-wire to 4-wire gain.

$$V_{TX} = (0.60196)(0.92601) = 0.55742V_{RMS} \quad \text{(EQ. 42)}$$

The design specifications require the gain from V_{2W} to V_{PCMOUT} equal 0dBm. This results in an output voltage at V_{PCMOUT} of $0.51769V_{RMS}$ or $-3.5dBm0_{(600\Omega)}$. (Note: $-2.19dBm0_{(811\Omega)} = -3.5dBm0_{(600\Omega)}$).

The gain from V_{TX} to V_{PCMOUT} is calculated in Equation 43.

$$G_{VTX-VPCMOUT} = \frac{0.51769}{0.55742} = 0.92872 \quad \text{(EQ. 43)}$$

Setting this gain equal to R_f / R_{a1} enables the value of R_f and R_{a1} to be determined (Equation 44).

$$\frac{R_f}{R_{a1}} = 0.92872 \quad \text{(EQ. 44)}$$

If R_f = 49.9kΩ then R_{a1} = 53.72kΩ

Closest standard value for R_{a1} is 53.6kΩ

The gain from V_{PWRO+} to V_{PCMOUT}, to achieve transhybrid balance is calculated in Equation 45.

$$G_{VPWRO+\ -VPCMOUT} = \frac{0.51769}{0.60196} = 0.86000 \quad \text{(EQ. 45)}$$

Setting this gain equal to R_f / R_{a2} enables the value of R_f and R_{a2} to be determined (Equation 46).

$$\frac{R_f}{R_{a1}} = 0.86000 \quad \text{(EQ. 46)}$$

If R_f = 49.9kΩ then R_{a2} = 58kΩ

Closest standard value for Ra1 is 57.6kΩ

Reference

[1] Website
www.ti.com/sc/docs/psheets/abstract/apps/slwa006.htm