Impedance Matching Design Equations for the HC5509 Series of SLICs

Application Note | October 1996 | AN9607.1

Introduction

The HC5509 Series of SLICs use feedback to synthesize the impedance at the 2-wire tip and ring terminals. The network is capable of synthesizing both resistive and complex impedances. Matching the SLIC's 2-wire impedance to the load is important to maximize power transfer and 2-wire return loss. The 2-wire return loss is a measure of the similarity of the impedance of a transmission line (tip and ring) and the impedance at it's termination. It is a ratio, expressed in decibels, of the power of the outgoing signal to the power of the signal reflected back from an impedance discontinuity.

This application note will discuss the basic DC operation of the tip and ring amplifiers for an understanding of the reaction between the tip and ring amplifiers, the requirements for impedance matching and the derivation of the design equations for calculating the required feedback components for both resistive and complex impedances. The analysis will use the HC5509B as the basis for the discussion. Design solutions for the HC5509A1R3060, HC5524 and HC5517 are provided in Table 1.

Tip and Ring Amplifiers

The tip and ring amplifiers are voltage feedback op amps that are connected to generate a differential output (e.g. if tip sources 20mA then ring sinks 20mA). Figure 1 shows the connection of the tip and ring amplifiers. The tip DC voltage is set by an internal +2V reference, resulting in -4V at the output. The ring DC voltage is set by the tip DC output voltage and an internal $V_{BAT}/2$ reference, resulting in V_{BAT} +4V at the output (see Equations 1, 2 and 3).

$$V_{TIP\ FEED} = V_C = -2V\left(\frac{R}{R/2}\right) = -4V \quad \text{(EQ. 1)}$$

$$V_{RING\ FEED} = V_D = \frac{V_{BAT}}{2}\left(1+\frac{R}{R}\right) - V_{TIP\ FEED}\left(\frac{R}{R}\right) \quad \text{(EQ. 2)}$$

$$V_D = V_{BAT} + 4 \quad \text{(EQ. 3)}$$

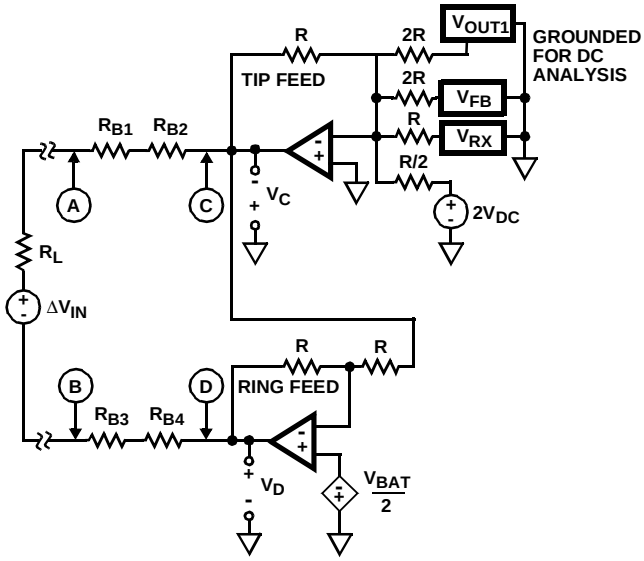


FIGURE 1. OPERATION OF THE TIP AND RING AMPLIFIERS

Requirements for Impedance matching

Impedance matching of the HC5509B application circuit to the transmission line requires that the impedance be matched to points "A" and "B" in Figure 2. To do this, the sense resistors R_{B1}, R_{B2}, R_{B3} and R_{B4} must be accounted for by the feedback network to make it appear as if the output of the tip and ring amplifiers are at points "A" and "B". The feedback network takes a voltage that is equal to the voltage drop across the sense resistors and feeds it into the summing node of the tip amplifier. The effect of this is to cause the tip feed voltages to become more negative by a value that is proportional to the voltage drop across the sense resistors R_{B1} and R_{B2}. At the same time the ring amplifier becomes more positive by the same amount to account for resistors R_{B3} and R_{B4}.

The net effect cancels out the voltage drop across the feed resistors. By nullifying the effects of the feed resistors the feedback circuitry becomes relatively easy to match the impedance at points "A" and "B".

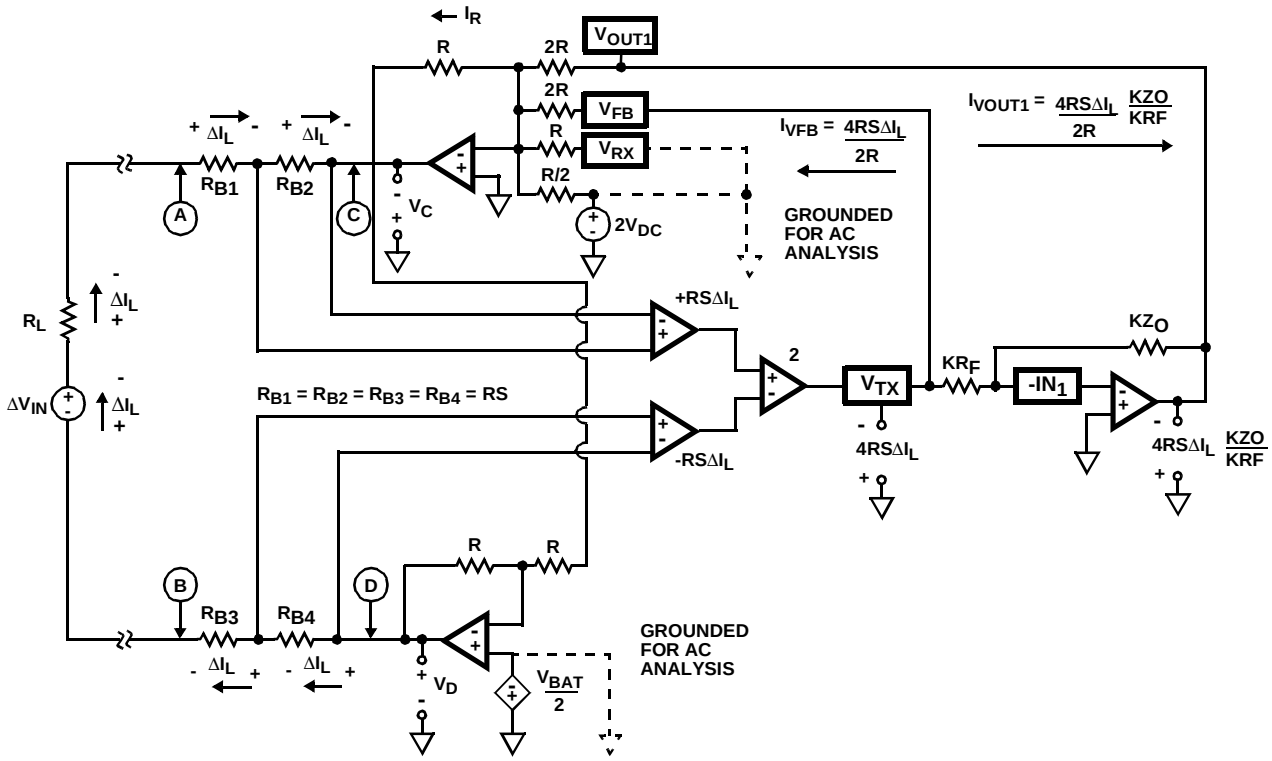


FIGURE 2. FEEDBACK NETWORK FOR IMPEDANCE MATCHING

Impedance Matching Design Equations

Before writing the loop equation to solve for the proper feedback to match the SLICs 2-wire impedance to the load, the AC voltage at V_C and V_D (Figure 2) must first be determined.

The feedback loop senses the loop current through resistors R_{B2} and R_{B4}. For the current direction shown in Figure 2 the VTX output is equal to $+4RS\Delta I_L$. The VTX outputs feedback into the tip current summing node via the VFB pin. The current into VFB is equal to:

$$I_{VFB} = \frac{4RS\Delta I_L}{2R} \quad \text{(EQ. 5)}$$

The VTX voltage is also feed into the -IN input of the SLIC's internal op amp. This signal is amplified by the ratio KZ0/KRF then feed into the tip current summing node via the VOUT1 pin. (Note: the VRX pin and the internal +2V reference are grounded for the AC analysis.) The current into the VOUT1 pin is equal to:

$$I_{VOUT1} = \frac{4RS\Delta I_L}{2R}\left(\frac{Z0}{RF}\right) \quad \text{(EQ. 6)}$$

Equation 7 is the node equation for the tip amplifier summing node. The current in the tip feedback resistor (I_R) is given in Equation 8.

$$-I_R + \frac{4RS\Delta I_L}{2R} - \frac{4RS\Delta I_L}{2R}\left(\frac{Z0}{RF}\right) = 0 \quad \text{(EQ. 7)}$$

$$I_R = \frac{4RS\Delta I_L}{2R} - \frac{4RS\Delta I_L}{2R}\left(\frac{Z0}{RF}\right) \quad \text{(EQ. 8)}$$

The voltage V_C is then equal to:

$$V_C = (I_R)(R) \quad \text{(EQ. 9)}$$

$$V_C = -2RS\Delta I_L\left(1 - \frac{Z0}{RF}\right) \quad \text{(EQ. 10)}$$

and the AC voltage at V_D is:

$$V_D = 2RS\Delta I_L\left(1 - \frac{Z0}{RF}\right) \quad \text{(EQ. 11)}$$

(Note $V_{BAT}/2$ is grounded for AC analysis)

Having the voltages at V_C and V_D, as a function of the feedback network, the loop equation to match the impedance of any load is as follows:

$$-2RS\Delta I_L\left(1 - \frac{Z0}{RF}\right) + 2RS\Delta I_L - \Delta V_{IN} +$$

$$L\Delta I_L + 2RS\Delta I_L - 2RS\Delta I_L\left(1 - \frac{Z0}{RF}\right) = 0 \quad \text{(EQ. 1:}$$

$$\Delta V_{IN} = -4RS\Delta I_L\left(1 - \frac{Z0}{RF}\right) + 4RS\Delta I_L + RL\Delta I_L \quad \text{(EQ. 13)}$$

$$\Delta V_{IN} = \Delta I_L\left[-4RS\left(1 - \frac{Z0}{RF}\right) + 4RS + R_L\right] \quad \text{(EQ. 14)}$$

$$\frac{\Delta V_{IN}}{\Delta I_L} = 4RS\left(\frac{Z0}{RF}\right) + R_L \qquad \frac{\Delta V_{IN}}{\Delta I_L} = 4RS\frac{Z0}{RF} + R_L \qquad \text{(EQ. 15)}$$

Equation 14 can be separated into two terms, the feedback term (-4RS(1 - ZO/RF) and the loop impedance term (+4RS + R_L). The +4RS term of the loop impedance is cancelled by the -4RS term of the feedback. The result is shown in Equation 15. Figure 3 is a schematic representation of Equation 15.

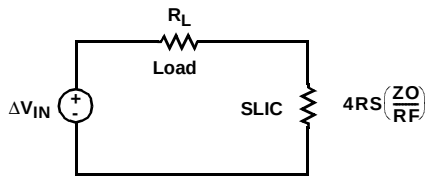


FIGURE 3. SCHEMATIC REPRESENTATION OF EQUATION 15

To match the impedance of the SLIC to the impedance of the load set

$$R_L = 4RS\left(\frac{ZO}{RF}\right) \qquad \text{(EQ. 16)}$$

If RF is made to equal 4RS then:

$$R_L = ZO \qquad \text{(EQ. 17)}$$

Therefore to match the HC5509B, with RS equal to 50Ω, to a 600 Ω load:

$$RF = 4RS = 4(50\Omega) = 200\Omega \qquad \text{(EQ. 18)}$$

and

$$R_L = ZO = 600\Omega \qquad \text{(EQ. 19)}$$

To prevent loading down the VTX output, the value of RF and ZO are typically scaled by a factor of K = 100, therefore:

$$KRF = 20k\Omega \qquad KZO = 60K\Omega \qquad \text{(EQ. 20)}$$

Since the impedance matching is a function of the voltage gain, scaling of the resistors to achieve a standard value is recommended.

For complex impedances the above analysis is the same.

$$KRF = 20k\Omega \qquad KZO = 100(Resistive) + \frac{Reactive}{100} \qquad \text{(EQ. 21)}$$

Table 1 list the values of KRF, KZO for several worldwide Typical line impedances. The analysis for the HC5509A1R3060, HC5524 and the HC5517 are similar to that of the HC5509B. The only exception is the HC5517 in that the VFB feedback path is not connected. Other than that the analysis are identical.

When matching a complex impedance some impedance models (900 + 2.15µF, K = 100) will cause the op amp feedback to be open at DC currents, bring the op amp to an output rail. A resistor with a value of about 10 times the reactance of the capacitor (21.6nF) at the low frequency of interest (200Hz for example) can be placed in parallel with

TABLE 1.

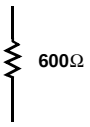
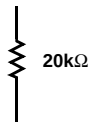
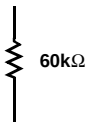
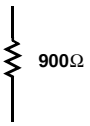
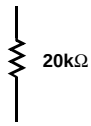
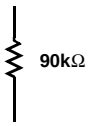
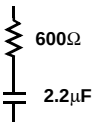
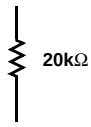
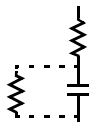
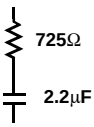
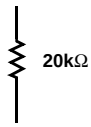
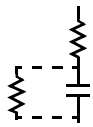
LOAD IMPEDANCE	KRF	KZO	OPTIONAL PARALLEL RESISTOR
HC5509B1: VFB CONNECTED			
 600Ω	 20kΩ	 60kΩ	NA
 900Ω	 20kΩ	 90kΩ	NA
 600Ω 2.2µF	 20kΩ	 60kΩ 22nF	360kΩ
 725Ω 2.2µF	 20kΩ	 72.5kΩ 22nF	360kΩ

TABLE 1. (Continued)

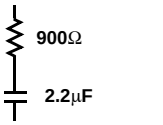
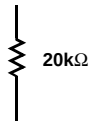
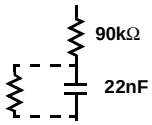
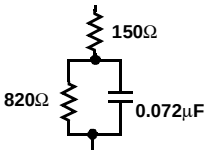
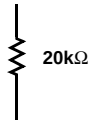
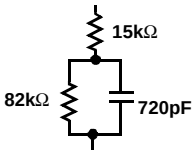
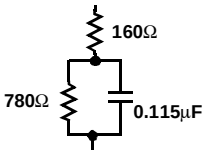
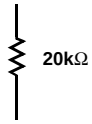
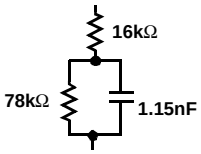
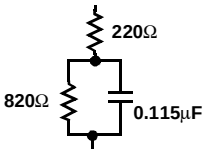
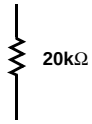
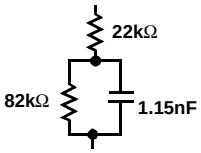
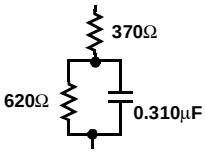
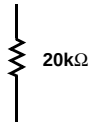
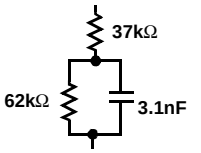
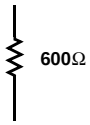
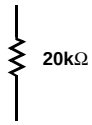
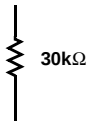
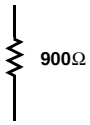
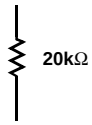
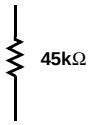
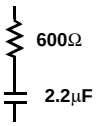
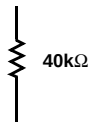
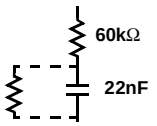
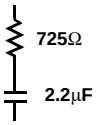
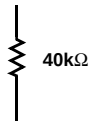
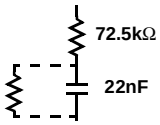
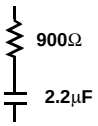
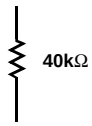
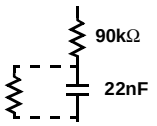
LOAD IMPEDANCE	KRF	KZO	OPTIONAL PARALLEL RESISTOR
			360kΩ
			NA
			NA
			NA
			NA
HC55509A1R3060: VFB CONNECTED			
			NA
			NA
			360kΩ
			360kΩ
			360kΩ

TABLE 1. (Continued)

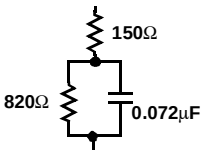
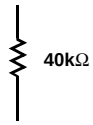
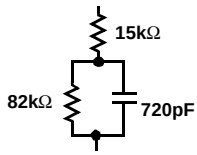
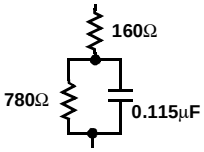
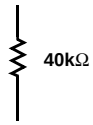
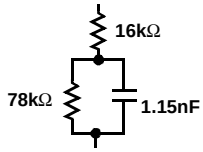
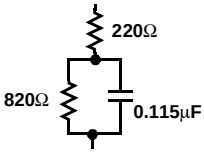
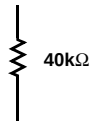
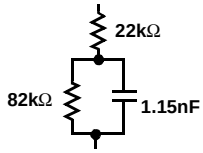
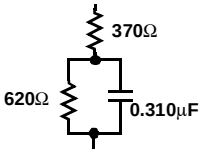
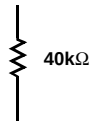
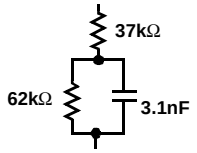
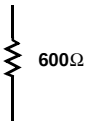
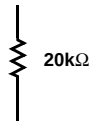
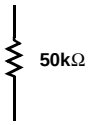
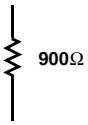
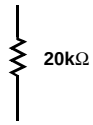
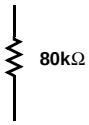
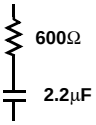
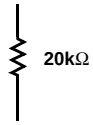
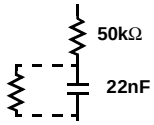
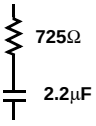
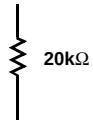
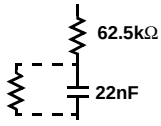
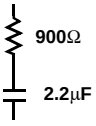
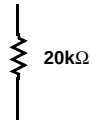
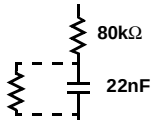
LOAD IMPEDANCE	KRF	KZO	OPTIONAL PARALLEL RESISTOR
			NA
			NA
			NA
			NA
HC5524: VFB CONNECTED. Single feed resistor for tip and one for ring.			
			NA
			NA
			360kΩ
			360kΩ
			360kΩ

TABLE 1. (Continued)

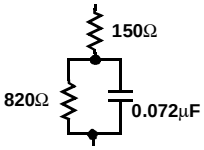
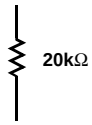
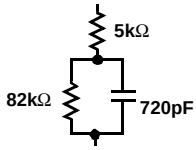
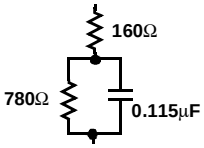
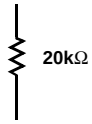
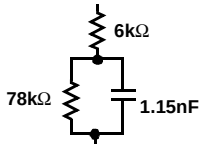
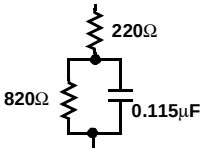
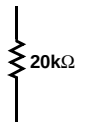
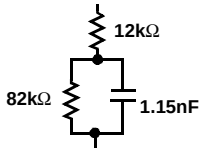
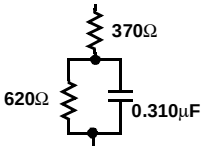
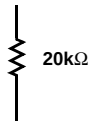
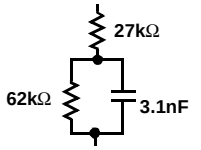
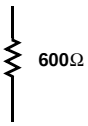
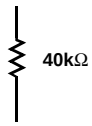
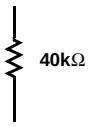
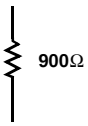
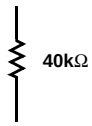
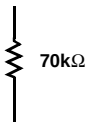
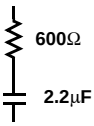
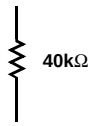
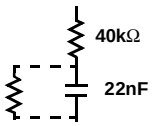
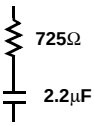
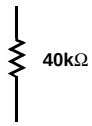
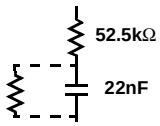
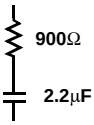
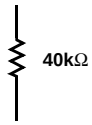
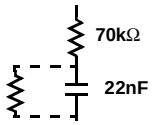
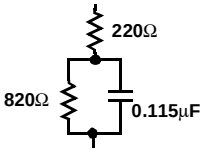
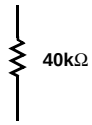
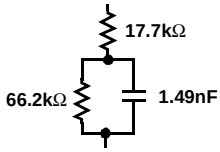
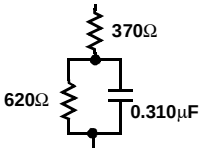
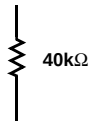
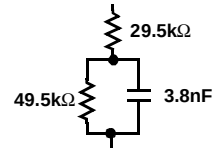
LOAD IMPEDANCE	KRF	KZO	OPTIONAL PARALLEL RESISTOR
			NA
			NA
			NA
			NA
HC5517: VFB NOT CONNECTED			
			NA
			NA
			360kΩ
			360kΩ
			360kΩ

TABLE 1. (Continued)

LOAD IMPEDANCE	KRF	KZO	OPTIONAL PARALLEL RESISTOR
			NA
			NA

littlediode
COMPONENTS FOR ALL

Littlediode supplies new, hard to find or obsolete electronic components and semiconductors all over the world.

With over two million different components listed you are sure to find the part you need.

Feel free to visit us today at our online store:

LittleDiode.com

Looking forward to providing you with the best possible service.