EE691 R&D project report, EE Dept., IIT Bombay, November 2004

Adaptive side-tone cancellation on telephone line for data communication applications

Sameer Kurolikar(03307912)
Supervisor: P.C.Pandey
Course Instructor : P.C.Pandey

Abstract

The report discusses adaptive side-tone cancellation for data communication applications that use telephone line as a medium. The high speed requirements in digital data communications are restricted by the side-tone present in full duplex networks. Simple balancing circuits are effective only upto limited attenuation levels. DSP based attenuators (echo cancellers) are much effective but too costly. A side-tone cancellation circuit has to be sufficiently effective as well as low cost. A simple active hybrid circuit using FET as a variable resistor is discussed. Low cost micro-controller can be used to vary the resistance of FET through PWM technique till the side-tone is cancelled completely or below acceptable level. The circuit has been experimentally tested for evaluating its performance for side-tone cancellation as a function of frequency.

1 Introduction

An electrical current is used to convey the information over telephone lines from one station to another [2]. Telephone lines are used for carrying not only speech signals but also digital data

When a telephone is in operation, the telephone service provider sends a constant dc current through the telephone. The variations produced in current, by microphone, reflect the signal to be transmitted. A speaker is used to convert the signals from electrical form back to speech. In simple situation, when two telephones connected to same local exchange want to communicate, they are put in the same loop by operating the switches in the local exchange. Hence both the telephones are now sharing same current. The variations produced in current by telephone at one end are converted to speech at the other end and those produced at other end are converted to speech at this end.

All this communication takes place over only two wires and hence the signals are all mixed. For proper communication, there has to be some way to separate these signals at either end. A device called hybrid is used to convert a two-wire signal to four-wire signal and vice versa.

1.1 Hybrid transformer

A traditional hybrid is a multiple winding transformer [1]. As shown in Fig 1, it actually consists of two interconnected transformers in one physical container. By electromagnetic coupling, signals are transferred between windings. Where coupling results in opposite fields, signal cancellation occurs. Thus two superimposed ac signals can be recovered. This type of hybrid is called passive hybrid circuit.

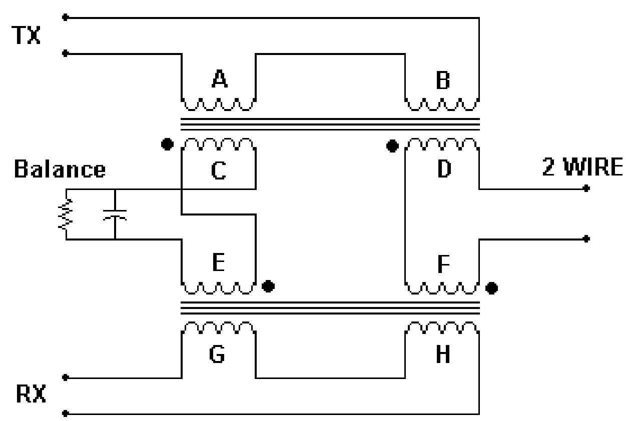

Figure 1: Hybrid Transformer. Adapted from [1]

1.2 Active hybrid

In active hybrid circuit, active elements like op-amp are used. Compare to passive hybrid, active circuits are more compact and can give better side-tone attenuation. Fig. 2 shows a typical active hybrid circuit [2]. In the circuit, Rn is the line impedance as seen by other side of the transformer. The circuit is said to be balanced if $R_1/R_3 = R_2/R_n$. In this condition, the line impedance is said to be exactly matched.

In both type of hybrid circuits, the effectiveness of separating two signals is dependent on the line impedance matching. Some balancing network is used along with hybrid, for

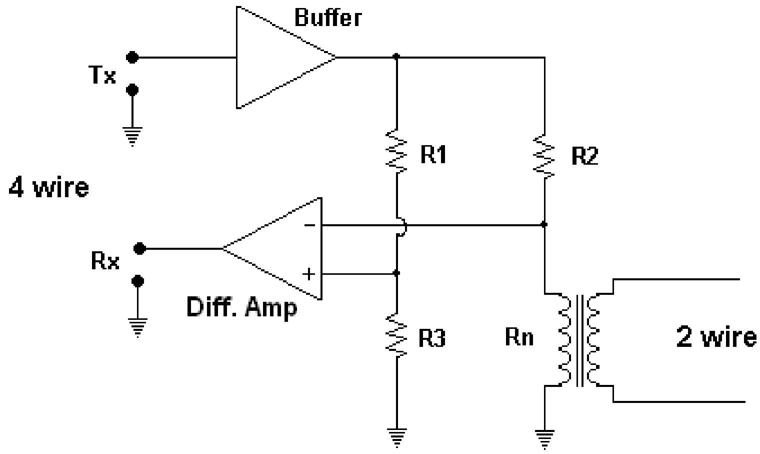

Figure 2: Active hybrid circuit. Adapted from [2]

compensating the mismatch of line impedance. However the balancing network cannot balance the impedances accurately and there is always small amount of transmitted signal that is fed back to the receiver of talking phone. This signal is called side-tone. In telephones traditionally used for only voice communications, this was a desirable feature because the talking person can listen his own voice from the receiver to determine how loudly to speak. Whereas today, telephones are being used for more than mere talking and side-tone may give a severe problem in some applications. A typical hybrid can give side-tone attenuation of around 20-30 dB [2].

2 Effect of side-tone in modems

While it is a desirable feature to have a small amount of side-tone in telephone circuits, it becomes a bottleneck for speed in data communication networks. In half-duplex data transmission, side-tone presents no problem since there is no receiver at the transmitting end. In case of full duplex transmissions, where the data signals are transmitted in both directions simultaneously, echoes from the data signal transmitted in one direction can interfere with the data signal flowing in opposite direction; unless these two data signals are in non-overlapping frequency bands [4]. In full duplex communications, due to bandwidth restrictions the modulation frequencies are closer to each other. It becomes difficult to identify the received signal separately from its own transmitted signal if side-tone is above some minimum level. Since the bandwidth of telephone line is limited, the separation between modulating frequencies cannot be increased. The only solution is to cancel or filter out the side-tone or echo (most commonly used word in modems) as much as possible.

3 Ways to cancel side-tone

Side-tone cancellation can be done by various methods. Many of today's modems use digital signal filtering techniques for canceling the side-tone effectively. Some of such techniques offer side-tone attenuation as high as 60 dB. Most of them are adaptive filtering techniques. Hence they also compensate for variations in line impedance as well as environmental noise. The software runs on the main processor or a dedicated DSP processor, which does the signal processing to filter out its own transmitted signal. If main processor of computer is used, the disadvantage is the reduced computer performance due to resource consuming. In case of a dedicated processor the cost of modem is drastically increased.

Another most commonly used way is balancing networks. Traditionally, these circuits have been adaptive but the side-tone cancellation was limited to 25dB only [1]. This limited the data rates to lower level.

A combination of balancing circuit along with some low cost processor can be better solution. This report discusses side-tone cancellation in telephone networks using resistive impedance matching. A low cost micro-controller can be used to tune the circuit so as to make it adaptive. Including a capacitive impedance matching can do more improvement in side-tone attenuation.

4 Adaptive circuit

The impedance of telephone line is a complex quantity. The resistance of the wire increases as the length of wire is increased. The capacitance between two wires is dependent upon environmental conditions. Variations in impedance make the fixed balance networks insufficient for side-tone cancellation. Modem standards like V.21, V.23, and BELL103 etc require the side-tone attenuation of at least 30 dB for their reliable operation [3]. As the impedance is variable, even if the distance of modem from exchange is fixed, side-tone may be present. Hence an adaptive circuit is required. Fig. 2 shows a typical active hybrid circuit.

5 Experimental evaluation

5.1 Evaluation of active Hybrid circuit

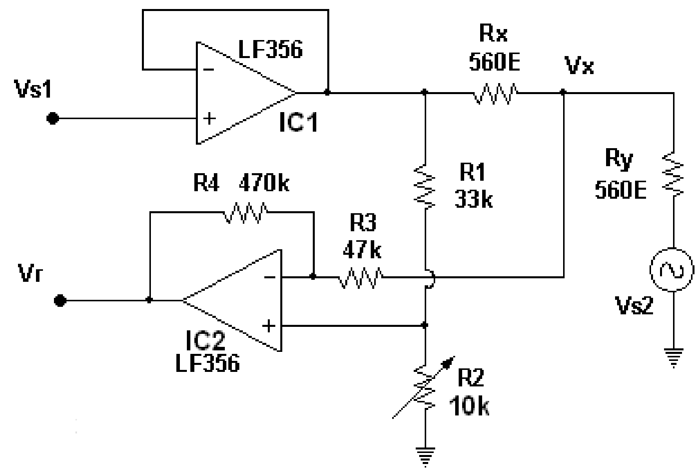

Figure 3: Experimental active hybrid circuit.

In the circuit in Fig. 3, V_{s2} is the signal coming from remote end and R_y is the line impedance at remote end. In ideal situation, the signal at V_r should not contain any part of V_{s1}.

From the circuit in Fig. 3, the voltage V_x due to signals at the two ends is,

$$V_x = V_{s1}\frac{R_y}{R_x + R_y} + V_{s2}\frac{R_x}{R_x + R_y} \tag{1}$$

Output of the circuit is given as,

$$V_r = -\frac{R_4}{R_3}V_x + \frac{R_2}{R_1 + R_2}V_{s1}\left(1 + \frac{R_4}{R_3}\right) \tag{2}$$

From (1) and (2), the output is given as,

$$V_x = -\frac{R_4}{R_3}\left(\frac{R_x}{R_x + R_y}V_{s2} + \frac{R_y}{R_x + R_y}V_{s1}\right) + \frac{R_2}{R_1 + R_2}\frac{R_3 + R_4}{R_3}V_{s1} \tag{3}$$

This can be written as,

$$V_r = \alpha V_{s1} + \beta V_{s2} \tag{4}$$

Where,

$$\alpha = \frac{R_2}{R_1 + R_2} \cdot \frac{R_3 + R_4}{R_3} - \frac{R_4}{R_3}\frac{R_y}{R_x + R_y} \tag{5}$$

$$\beta = -\frac{R_4}{R_3} \cdot \frac{R_x}{R_x + R_y} \tag{6}$$

Since, we don't want any locally transmitting signal to appear at local receiving end, α has to be zero. Hence

$$1 + \frac{R_1}{R_2} = \left(1 + \frac{R_3}{R_4}\right)\left(1 + \frac{R_x}{R_y}\right) \tag{7}$$

In ideal situation $R_x = R_y$ i.e. impedances are exactly matched then,

$$1 + \frac{R_1}{R_2} = 2\left(1 + \frac{R_3}{R_4}\right) \tag{8}$$

If we select $R_3 = R_4$, then the balance condition of (8) results in $R_1 = 3 \cdot R_2$.

In case of unbalanced condition, the signal at V_{s1} will appear at V_r as side-tone and by varying R_2, the side-tone can be nulled. For adaptive side-tone cancellation, some technique will be required for varying the resistor R_2 electronically so that the side-tone can be nullified.

5.2 Use of FET as variable resistor

Digital potentiometer is one of the easiest solutions for digitally varying resistor. But in that case, only finite resolution will be available, depending upon the selected integrated circuit. Although it is impossible to have infinite resolution with digital control systems, an element that can be varied continuously can be used as a variable resistor. One good option can be a FET (field effect transistor). In FET, the source to drain resistance R_{ds} is a function of gate control voltage. Hence by varying the gate control voltage, the resistance between source and drain can be varied. The resistance R_{ds} is also dependent on source to drain voltage V_{ds} and this causes signal distortion. The solution on this problem is feeding some part of V_{ds} to gate, along with the control voltage. This solution does not solve the problem completely and there is still some distortion. To further limit the distortion, V_{ds} itself should be kept low.

A FET based variable resistance circuit for side-tone cancellation is shown in Fig. 4 Experiment was performed to check the relation between gate control voltage V_c and resistance R_{ds}. Amplifier shown in the diagram is non-inverting amplifier to provide amplification to the signal to be observed because it is very small. It also provides high input impedance so avoiding loading of the resistor divider circuit. The relation of gate control voltage and R_{ds} is shown in Fig 5 graphically.

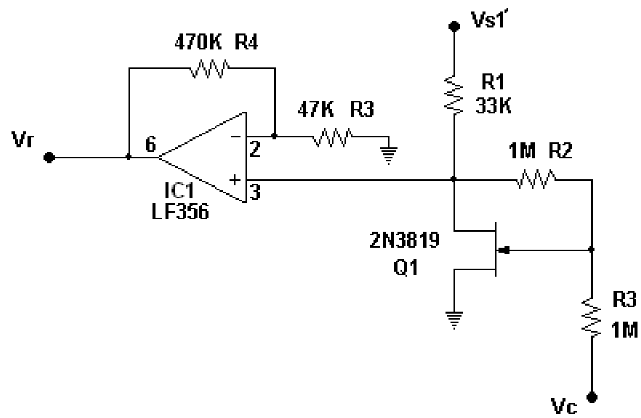

Figure 4: Experimental circuit for FET.

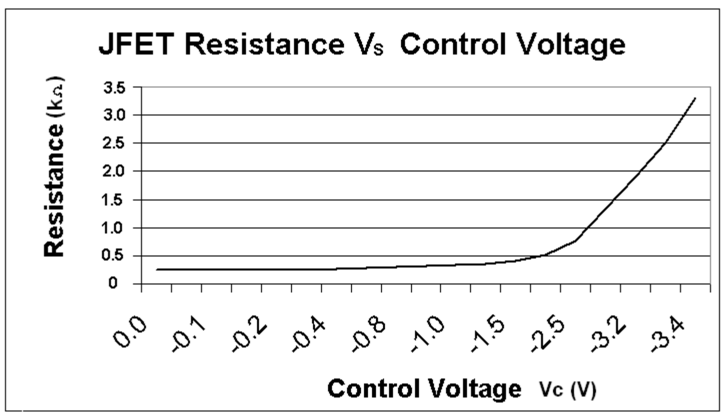

Figure 5: Relation between gate control voltage and resistance.

5.3 Side-tone attenuation using FET resistor

A circuit of active hybrid and FET as variable resistor is shown in fig 6. Experiment was performed by applying sinusoidal signal of various frequencies at V_{s1} and taking readings of control voltage for minimum possible V_r when V_{s2} is zero. A negative dc control voltage is used to vary the resistance of FET. Then for same control voltage, V_{s1} was made zero and signal applied to V_{s2} and output V_r was measured. In experiment, the applied non-zero voltage is of amplitude 4Vpp. Table 1 shows all the values of applied control voltage, minimum possible side-tone and desired output for same control voltage.

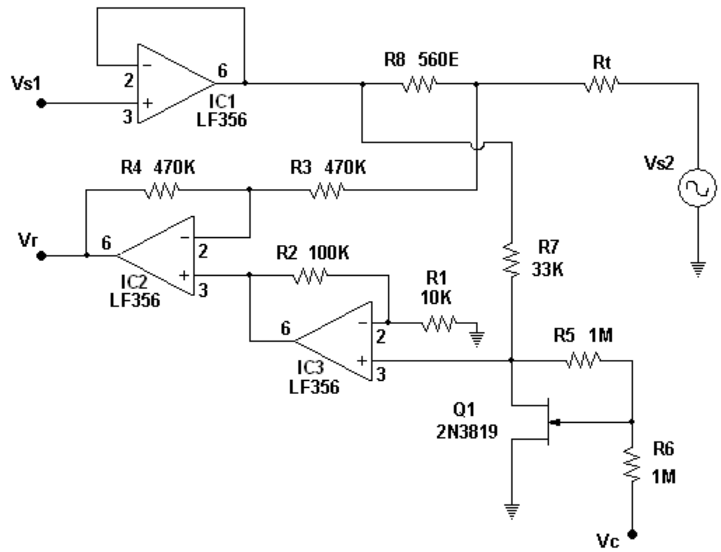

Figure 6: Side-tone attenuation using FET as a variable resistor.

Following are the notations used in the table 1. All voltages are peak-to-peak.

$$F = \text{Frequency of the signal applied.}$$

$$V_{c1}, V_{c2}, V_{c3} = \text{Control voltages applied to FET for } R_t = 560ohm, 1k \text{ and } 2k \text{ to get minimum possible side-tone when } V_{s2} = 0.$$

$$V_{r11}, V_{r21}, V_{r31} = \text{Obtained minimum possible side-tone.}$$

$$V_{r12}, V_{r22}, V_{r32} = \text{Output of circuit keeping same control voltage } V_c \text{ and signal applied to } V_{s2} \text{ while } V_{s1} = 0.$$

5.4 Adaptive tuning using microcontroller

For tuning the circuit using microcontroller, PWM technique can be used. The control voltage given to FET will be proportional to duty cycle of the PWM signal applied. The frequency of the control signal should be much higher compare to response time of the controlled element (here FET) so that the discrete nature of digital control signal doesn't appear. A low pass filter can be introduced to filter out the signal. Hence the average value of the PWM will be applied to the FET. The time constant of the low pass filter

Table 1: Side-tone as a function of signal frequency and control voltage

F (Hz)	V_{c1}	V_{r11}	V_{r12}	V_{c2}	V_{r21}	V_{r22}	V_{c3}	V_{r31}	V_{r32}
300	−2.55	0	1.9	−2.79	0	1.4	−2.92	0	0.9
500	−2.55	0.01	1.9	−2.79	0	1.4	−2.92	0.01	0.9
1k	−2.55	0.015	1.9	−2.79	0.02	1.4	−2.93	0.03	0.9
2k	−2.54	0.03	1.9	−2.78	0.04	1.4	−2.94	0.06	0.9
5k	−2.54	0.06	1.9	−2.77	0.09	1.4	−2.92	0.10	0.9
8k	−2.56	0.1	1.9	−2.76	0.14	1.4	−2.96	0.18	0.9

can be chosen so that only small ripple appears at its output while the response characteristics of the circuit does not degrade considerably.

For measurement of side-tone, a single bit ADC or comparator would be appropriate since, we want to measure only binary value. The side-tone will be compared with some threshold value and output of comparator will be either high or low depending on the value of side-tone. Before the signal can be fed to comparator, it should be rectified, to make it unipolar. We need precision rectifier circuit because the amplitude of the signal to be rectified is very small. The output of the comparator will be fed to microcontroller, and the microcontroller will vary the duty cycle of control signal to tune the circuit.

The complete schematic using hybrid circuit, precision rectifier and microcontroller is shown in Fig. 7.

6 Conclusion

In worst case of frequency 8 kHz and line impedance of 2 kΩ, the side-tone attenuation obtained was 26.94 dB. The bandwidth of telephone line is limited to 3.2 kHz. Compare to that, 8 kHz gives much larger margin. In normal opration, the maximum frequency can be considered to be below 5 kHz. The side-tone attenuation at 5 kHz for line impedance of 2 kOhm is 32 dB. This much attenuation is sufficient for modem standards like V.21, V.23 and BELL103.
An improvement in side-tone attenuation can be achieved by compensating for capacitive impedances. Use of FET as a variable resistor provides low cost solution for digital control.

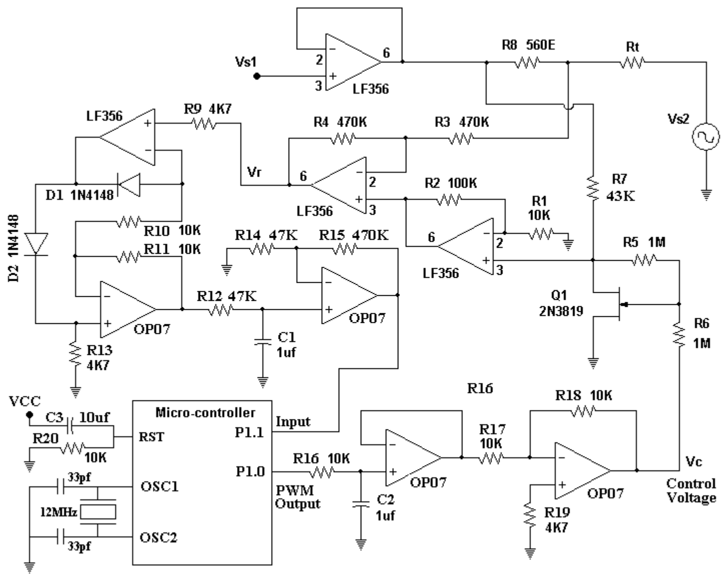

Figure 7: Adaptive side-tone cancellation using microcontroller

References

[1] S. Bigelow, J. Fike and, G. Friend, *Understanding Telephone Electronics*, Third Edition, Indiana: Heyden Books, 1991.

[2] "Telephone interfacing circuits," http://www.hut.fi/misc/Electronics/circuits/teleinterface.htm, Helsinki university of technology. Accessed on october 2004.

[3] "Application note on ST75C52/ST75C520 - Single Ended and Single Power Supply Hybrid Circuit," ST Microelectronics, http://www.st.com.

[4] D.G.Messerschmitt, "Echo cancellation in speech and data transmission," *IEEE Journal on Selected Areas in communication,* Vol. SAC-2, NO. 2, March 1984.