
EMI/ESD Filters for Cellular Phones

Abstract

Cellular phones, as with all handheld and wireless devices are susceptible to the damaging effects of Electrostatic Discharge (ESD) transients. As much as 40KV of ESD can be generated by the human body or through air discharge. In addition, cellular phones, because of their higher operating frequencies, are more sensitive to EMI/RFI interference. Global authorities are now imposing very strict regulations to ensure that cellular phones are electrically 'clean' before being released to the market.

About EMI

EMI (Electromagnetic interference) is the disruption of operation of an electronic device when it is in the vicinity of an electromagnetic field (EM field) in the radio frequency (RF) spectrum that is caused by another electronic device. EMI consists of any unwanted, spurious, conducted, and/or radiated signals of electrical origin that can cause unacceptable degradation of system or equipment performance. The effects of EMI can range from minor nuisance to catastrophic consequences.

The coupling path may involve one or more of the following mechanisms

- Conduction – electric current
- Radiation – electromagnetic field
- Capacitive Coupling – electric field
- Inductive Coupling – magnetic field

About ESD

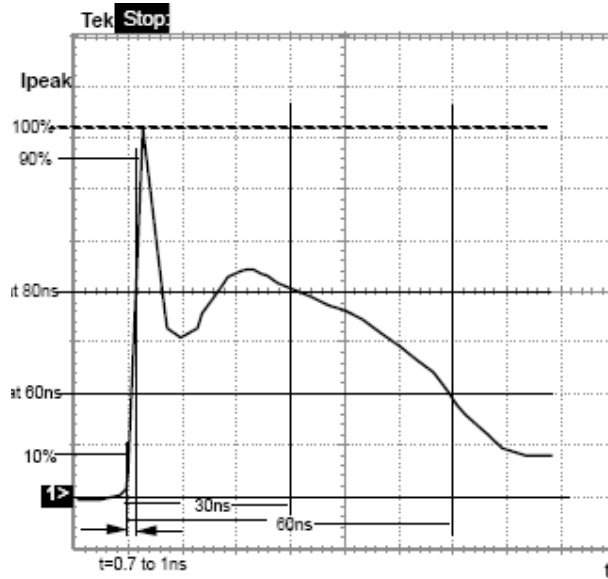
ESD (Electrostatic discharge) is the transfer of an electrostatic charge between two objects. When two insulating materials are rubbed together, an electric charge builds up between them (as electrons are stripped off one surface and deposited on the other surface). The surface with the excess of electrons becomes negatively charged, and the surface with the shortage of electrons becomes positively charged. This effect is known as the “triboelectric” effect (the action of rubbing). Electrostatic voltage is then a function of the separation of the materials in the series, the intimacy of contact, and the rate of separation. Therefore, any time there are two nonconductive materials flowing in opposition to each other, an electrostatic voltage will be generated. The level of electrostatic potential generated depends on the relative charge affinity between materials, the humidity, and other factors.

ESD is one of the main causes of device failures in the semiconductor industry.

ESD Transients are normally

- Less than 8.4μs in duration
- Characterized by sinusoidal or exponential waveform
- Normally associated with high impedance sources
- Can range from a few millivolts to 18,000 Volts under normal conditions

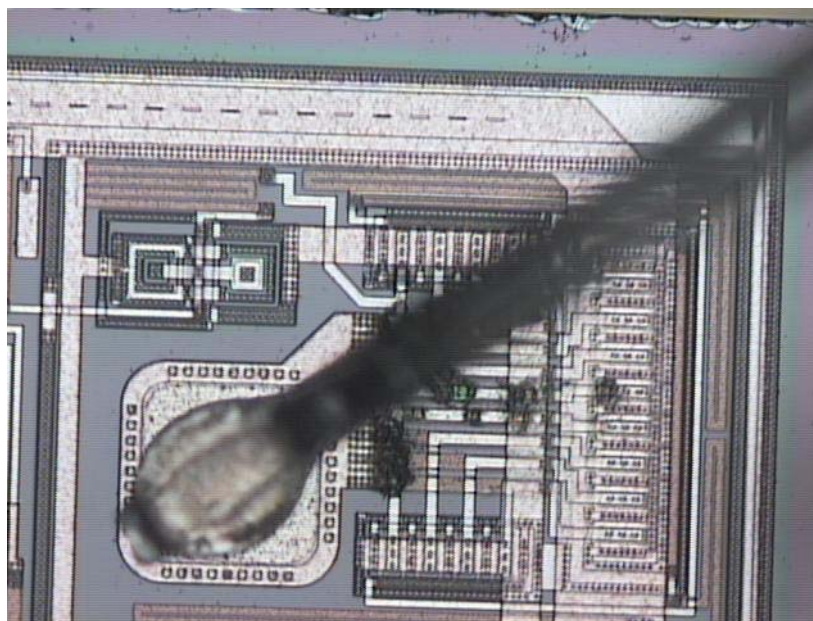
The IEC 61000-4-2 (ESD) transient is characterized as shown below:



Level	Indicated Voltage (KV)	First peak current of discharge (A)	Rise Time t_r (ns)	Current at 30ns (A)	Current at 60ns (A)
1	2	7.5	0.7 to 1	4	2
2	4	15	0.7 to 1	8	4
3	6	22.5	0.7 to 1	12	6
4	8	30	0.7 to 1	16	8

A double exponential waveform with a rise time t_r of 0.7ns to 1.0ns and fall time of 30ns measured at 50% of the decay.

If not suppressed, an ESD transient applied to the external interface of a cell phone causes untold permanent and latent damage to sensitive CMOS type devices. The picture shown below is actual damage on a transceiver chip that contained 2kV internal protection for manufacture handling. The transient applied was 8kV contact discharge as per IEC 61000-4-2.



Traditional EMI I/O Filter Options

There are several filter design choices available to attenuate the noise entering and exiting an I/O port, including ferrite beads, feed-through capacitors, filter connectors and Pi or Tee filters. These traditional filter devices have been used for a number of years to solve EMI problems; however, these devices tend to be relatively expensive and large in size.

A brief discussion of the different filtering options available to a designer is given in the follow paragraphs. A summary of the advantages and disadvantages of the filter devices is shown in Table 1 as following.

Table 1. EMI Filter Device Options

EMI Device	Filtering Mechanism	Advantages	Disadvantages	Package Availability
Ferrite Beads	Series attenuation	<ul style="list-style-type: none"> • Low cost • “Slip-on” package does not require PCB modification 	<ul style="list-style-type: none"> • Relatively large in size • Ferrite material saturates at high DC currents 	<ul style="list-style-type: none"> • Discrete devices • “Slip-on” beads • Integrated package
Feedthrough Capacitors	Shunt attenuation	<ul style="list-style-type: none"> • Signal is filtered before PCB entry • Small impedance at ground connection • Effective in segmented chassis designs 	<ul style="list-style-type: none"> • High cost • Relatively large in size • Difficult to use on PCB • Tee filter frequency characteristics are dependent on source (cable) and load (receiver) impedances 	<ul style="list-style-type: none"> • Chassis mounting
Filter Connectors	Shunt attenuation	<ul style="list-style-type: none"> • Signal is filtered before PCB entry • Small impedance at ground connection • Effective in segmented chassis designs 	<ul style="list-style-type: none"> • High cost • Connector size increases 	<ul style="list-style-type: none"> • Chassis mounting
RC Filters	Shunt attenuation	<ul style="list-style-type: none"> • Current limiting via resistance • Rs are smaller than Ls 	<ul style="list-style-type: none"> • dV/dt limiting, but no voltage clamping for ESD • Filter circuit located on PCB • 1st order LPF with -20 dB/decade attenuation • Rs have insertion loss/power dissipation 	<ul style="list-style-type: none"> • Discrete devices • Integrated package
LC Filters	Shunt attenuation	<ul style="list-style-type: none"> • 2nd order LPF with -40 dB/decade attenuation • di/dt limiting via inductance • Ls have low insertion loss/power dissipation 	<ul style="list-style-type: none"> • Filter will amplify at self resonance frequency • Filter circuit located on PCB • Ls are bigger than Rs • ESD voltage is not clamped 	<ul style="list-style-type: none"> • Discrete devices • Integrated package

Ferrite Beads

Ferrite beads are a series filter device that provides high frequency attenuation with a small resistive power loss at DC and low frequencies. At low frequencies, the device functions as a resistor with a resistance that is typically equal to 50 to 200 ohms. At high frequencies, the device functions as an inductor and has an impedance that increases with frequency. The equivalent model for a ferrite bead is shown in Figure 1. These devices are very effective for solving problems such as the “ringing” noise that often is imposed on high-speed digital signals.

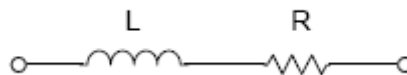


Figure 1. Ferrite bead equivalent circuit

Feed-through Capacitors and Filter Connectors

Feed-through capacitors and filter connectors are shunt filter devices that are typically mounted on a conductive chassis or a shielded enclosure. The mechanical mounting forms the

ground connection and the high frequency noise is shunted to the chassis ground instead of signal ground. Thus, the noise signal is filtered before the signal reaches the PCB. The effectiveness of the filter is usually very good because the inductance associated with the ground connection is minimized. These devices are very effective for designs that have separate compartments in the enclosure where the filters are used to connect the EMI “clean” and “dirty” segregated portions of the design.

Figure 2 shows the schematic representation of a feed-through capacitor, which is essentially a Tee filter where the resistors and/or inductors are formed by the impedance of the driver circuit and the I/O cable. Filter connectors are available in a number of circuit configurations and the most popular type is a Tee filters made with feed-through capacitors. Figure 3 shows the schematic representation of a feed-through capacitor based filter connector.

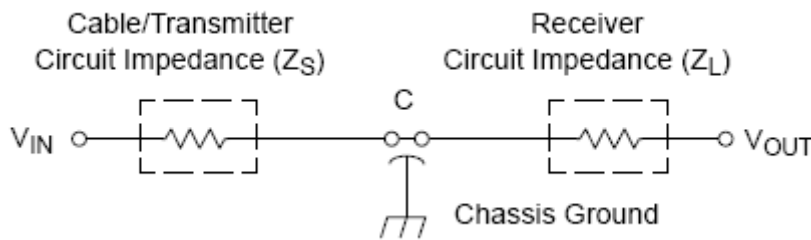


Figure 2. Feed-through capacitor equivalent circuit

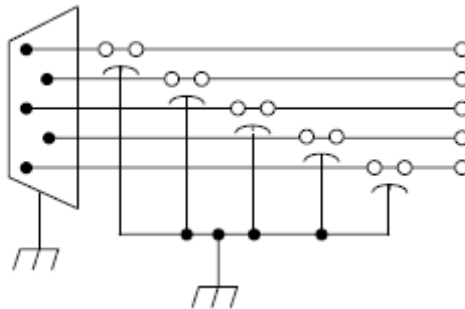


Figure 3. Filter Connector with Feed-through Capacitors

Pi and Tee Filters

The two most popular bi-directional low pass filter configurations are Pi and Tee filters. Pi and Tee filters can be constructed using discrete components, integrated discrete components, or an IPD device that uses zener diodes as the capacitive elements. These filters are typically mounted on a PCB and attenuate the noise to signal ground, in contrast to the enclosure mounted filters that attenuate the noise to chassis ground. Although it is usually more desirable to shunt the noise signal to chassis ground, PCB mounted filters are very effective if the devices can be located in close proximity to the I/O connector.

Pi and Tee filters can be constructed from either LCs or RCs as shown in Figures 4 through Figure 7. These circuits attenuate the noise signals that are both entering and exiting the filter network. In the Pi filter, R1 (L1) and C1 form a filter that attenuates the high frequency signals entering the network via the I/O cable, while R1 (L1) and C2 attenuates the high frequency noise that is exiting the network. In a similar manner, the Tee filter uses R1 (L1) and C1 as a filter to attenuate the incoming signals and R2 (L2) and C1 to attenuate the outgoing signals.

It is necessary to add a transient voltage suppression device such as a zener diode in order to provide ESD protection to the basic Pi or Tee filter. If two zeners are added to the Pi circuit, as shown in Figure 8, the ESD input voltage can be clamped to a non-destructive voltage level that

is equal to the zener voltage of the diode. In contrast, a RC or LC filter will only limit the voltage slew rate of the ESD input and will not clamp the ESD voltage.

The LC and RC Pi and Tee filters can be designed to be functionally equivalent as shown in Figure 9; however the LC filters are second order filters with a frequency attenuation roll-off of -40dB/decade , while the RC filters have a roll-off of -20dB/decade . The decision to use either a LC or a RC filter is usually based on the amount of power that will be dissipated in the L or R elements. The voltage drop of the resistor in RC filters is often too large for high current circuits; thus a LC filter is the preferred device for applications such as power line filters. For applications such as digital data lines, the voltage drop of the resistance is often insignificant. The insertion loss of the filter is usually not an issue in digital applications and either LC or RC filters can be used because typically the driver circuit output impedance is small (i.e. $Z_S \approx 0$) and the receiver circuit's input impedance is high (i.e. $Z_L \approx \infty$).

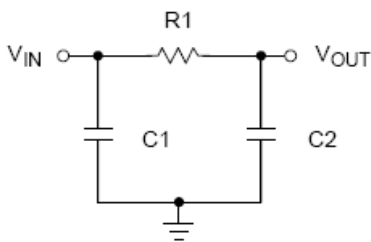


Figure 4. RC Pi Filter

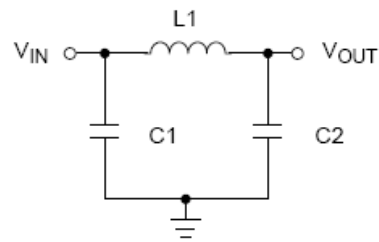


Figure 5. LC Pi Filter

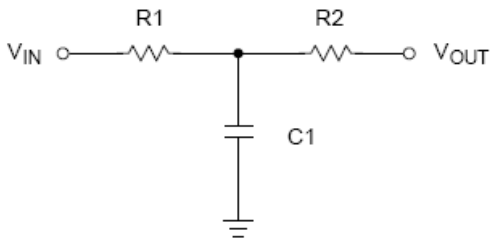


Figure 6. RC Tee Filter

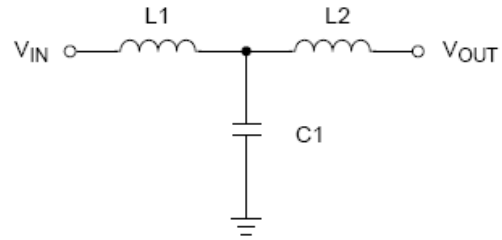


Figure 7. LC Tee Filter

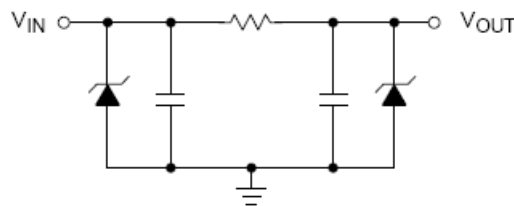


Figure 8. Discrete Pi Filter with ESD Protection

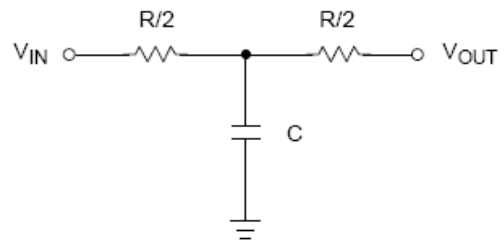
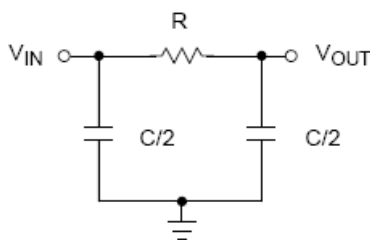


Figure 9. Equivalent RC Pi and Tee Filters

Selecting an EMI Filter

A procedure for selecting an EMI filter is shown in Figure 10. This procedure is intended to be a guideline to aid the designer in selecting an effective filter configuration to meet the EMI and ESD design requirements. In addition, this procedure illustrates some of the design issues that need to be analyzed in order to optimize the EMI/ESD solution. This procedure can be used to select any of the various filter devices.

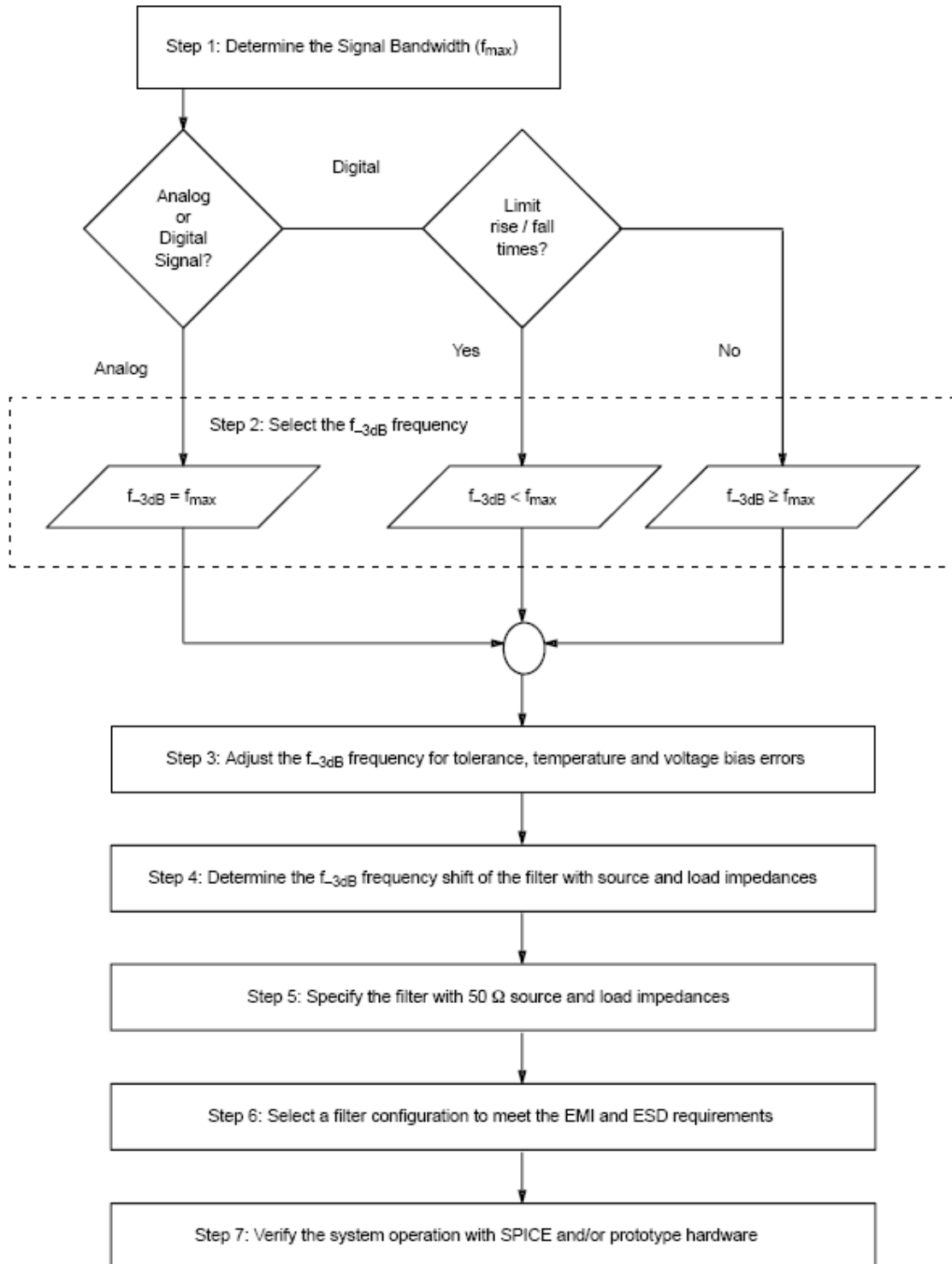


Figure 10. Selecting an EMI Filter

Union EMI/ESD Filter Devices

Responding to the need for space-efficient, noise filtering and ESD protection components, Union semiconductor has introduced a series of convenient devices:

- UM1002: Dual channel EMI/ESD Protection
- UM4401: Four Line EMI/ESD Protection
- UM6401: Six Line EMI/ESD Protection
- UM8401: Eight Line EMI/ESD Protection

Union EMI/ESD Filters are designed and characterized to safely dissipate ESD strikes at levels well beyond the maximum requirements set in the IEC 61000-4-2 standard. The IEC 61000-4-2 (ESD) pulse requires 8KV (contact) and 15KV (air discharge). All I/Os are rated at greater than $\pm 25kV$ using the IEC 61000-4-2 (1/30nSec) contact discharge method. Using the MIL-STD-883D (Method 3015) specification for Human Body Model (HBM) ESD, all pins are protected for contact discharges to greater than $\pm 30kV$.

The C-R-C combination of the EMI filter device will filter out high frequency signals such as 800 MHz, 900MHz and 1900MHz that are frequencies used by most GSM cellular phones. It will also attenuate Bluetooth and Wireless LAN 802.11B (2.4GHz) frequencies better than $-25dB$. High integration of the components minimizes the parasitic self-inductances and, compared to discrete solutions, provides much better attenuation.

The C-R-C filter also acts as a two-stage ESD protection circuit, by utilizing the TVS diodes that are designated as the capacitive part of the low pass PI filter. The first stage D1 will clamp (V_{c1}) the incoming transient and the second stage D2 will clamp (V_{c2}) any residual pulse that passes through the first stage.

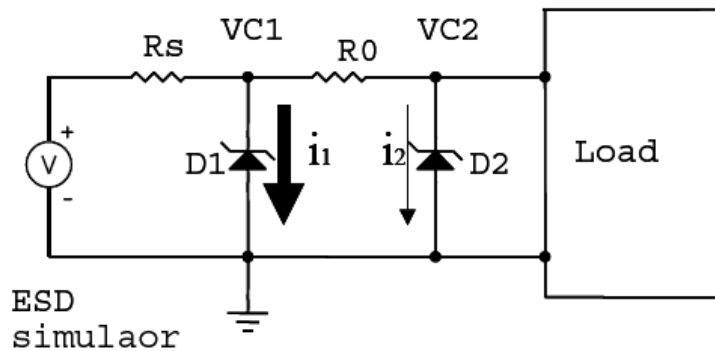


Figure 11. Two-Stage ESD Protection Circuits

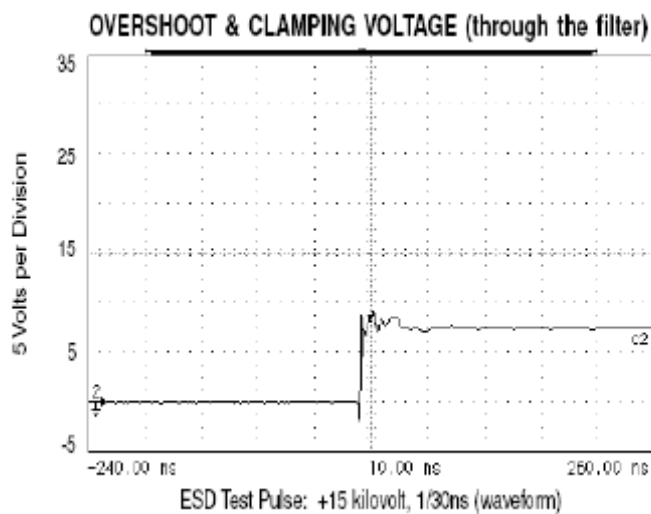


Figure 12. Overshoot and Clamping Voltage

In a cellular phone, the jack of the headset reproducer forms an open path for the ESD, and the audio port comes to be where the EMI flows in and out. Therefore EMI/ESD filter is absolutely a must. The UM1002 which provides a bi-directional filter and ESD Protection will be an ideal choice in these applications. Figure 13 and Figure 14 illustrate its pin configuration and protection circuit.

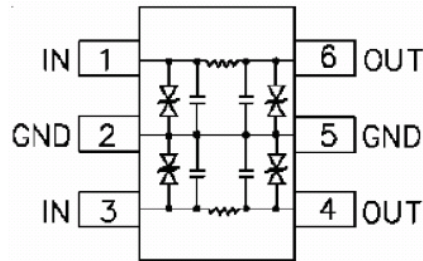


Figure 13. Pin configuration

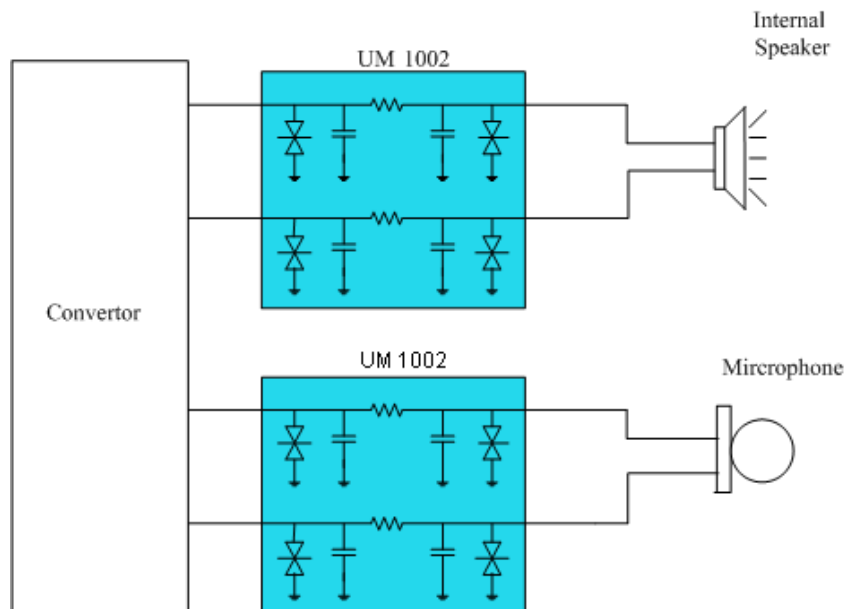
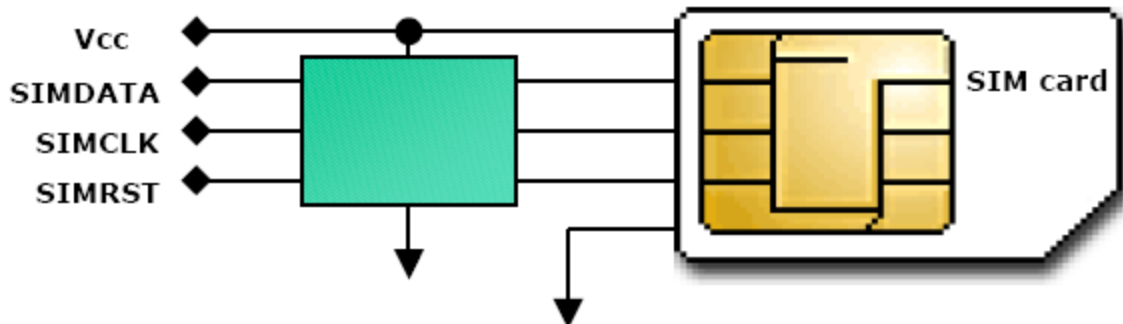


Figure 14. Protection Circuit

The UM4401 provides a bi-directional filter and ESD protection for all the signals and power line on the SIM. SIM cards are found in all GSM cellular phones and in other handheld devices and card readers.



The TVS diodes protect the controller against possible ESD transients that may occur when connector pins are exposed for insertion and removal of the SIM card.

The EMI filter suppresses all high frequency noise, preventing the unwanted EMI signal from both entering and exiting the main board. The signals that interface with the SIM card (Reset, Clock and bi-directional data) is also cleaned up by the filter characteristics removing unwanted spikes preventing data corruption.

For best results both ground bumps should be directly connected to the ground plane. An additional 1μF is required for stability of the supply rail. The typical application circuit is illustrated as following.

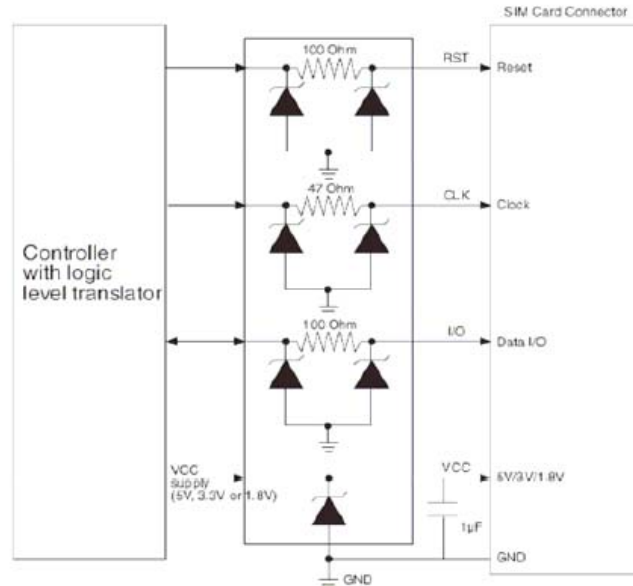


Figure 15 Typical Application Circuit for SIM Card Interface

The UM6401 contains 6 Filters in a 3.0mm x 1.6mm DFN package. Each is an independent second-order -40dB/decade low pass filter, the component values are 10pF-100Ω -10pF. This allows a cutoff frequency of 150MHz and an attenuation of greater than -30dB for the frequency band 800MHz to 2.5GHz.

The UM8401 contains 8 Filters in a 4.0mm x 1.6mm DFN package. Each is an independent second-order -40dB/decade low pass filter, the component values are 10pF-100Ω -10pF. This allows a cutoff frequency of 150MHz and an attenuation of greater than -25dB for the frequency band 800MHz to 2.5GHz.

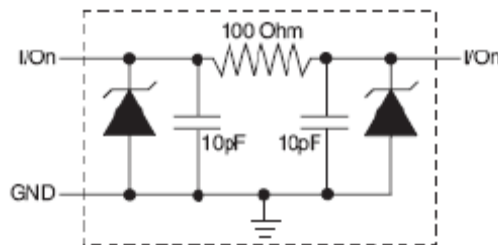


Figure 16. EMI Filter (for each channel)

In standby mode, the integrated TVS filter has a very low leakage current make it suitable for battery powered handheld devices. In addition, the low profile durable DFN package is useful in many applications.

Digital Crosstalk between the adjacent channels for the cutoff frequency and maximum attenuation is minimal as shown in the figures below.

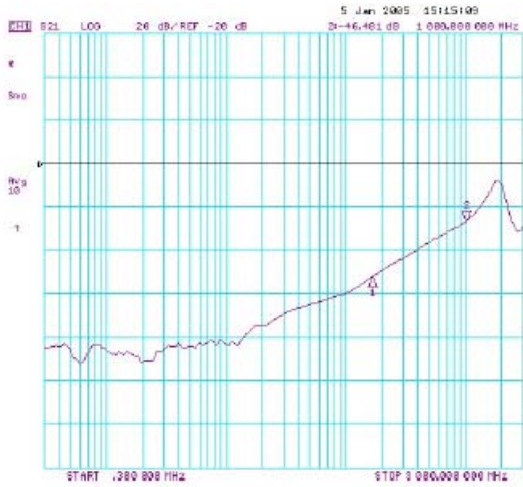


Figure 17. Adjacent Channel Crosstalk

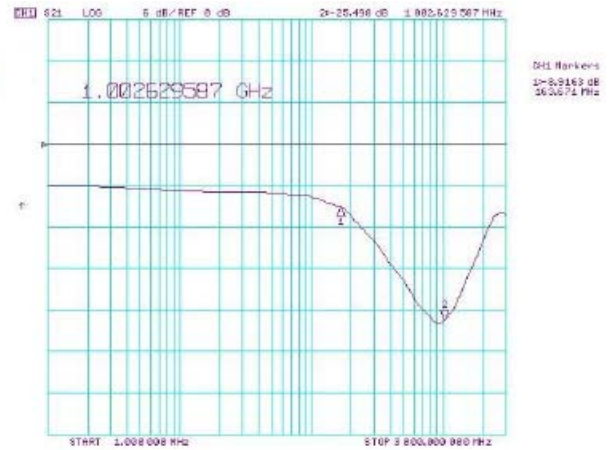
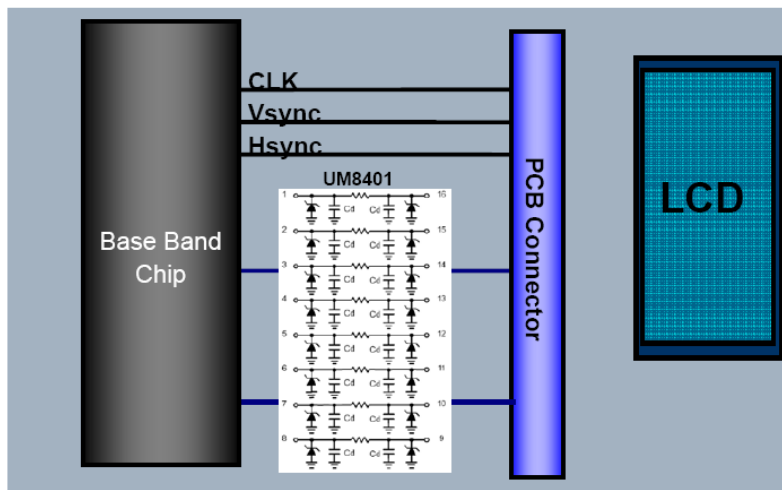
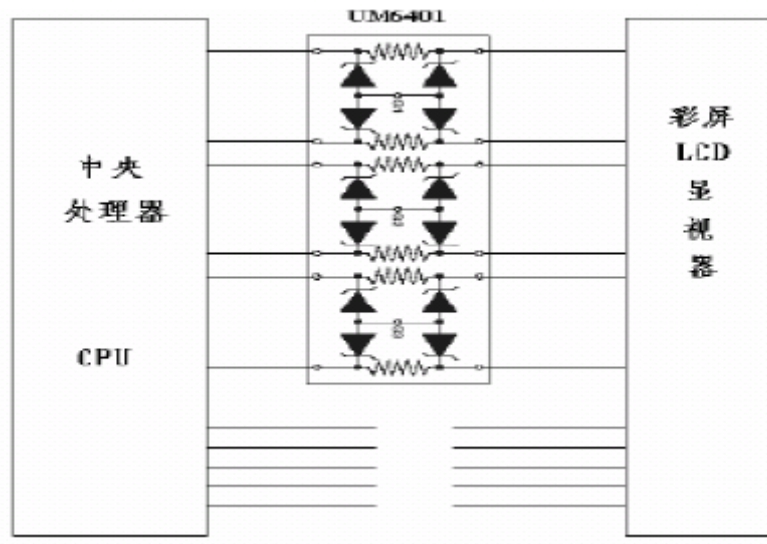


Figure 18. Attenuation at 1.0GHz

The UM6401 and UM8401 have been optimized for EMI filter and ESD protection of color LCD panels in cellular phones and other portable electronics, typical circuits are as follow.



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