

Even mode impedance — an introduction

Background

Coupled lines are usually designed to be driven differentially; in this case signals propagating along the line will encounter the differential impedance. This is lower than the impedance of the line on its own as the influence of the equal and opposite polarity of the two propagating signals makes the structure behave as though an extra ground plane has been added vertically between the traces. Though this is an "imaginary" or "virtual" ground its influence is the same as a real copper wall.

However, not all signals on a pair of coupled lines will be differential; the simplest example to take is electrical noise. One reason for using differential pairs is that a low level signal can be faithfully reproduced at the receiver in a electrically noisy environment. Because the traces are close, they will suffer from identical noise exposure. Noise induced on the pair will be of both equal amplitude *and* polarity. So while the original signal has equal and opposite polarity and feels the influence of the virtual ground, the noise will encounter no such ground. In fact as the noise is equal on both traces, the effect is to slightly increase the impedance of both traces. The impedance seen by the noise as it propagates is therefore the *even mode* impedance.

Definitions of impedance related terms:

Single ended Z_0 : The impedance seen when testing a single line which is not coupled to an adjacent line.

Differential (Z_{diff}): The impedance testing between a pair of lines when driven by equal and opposite polarity signals. (Z_{diff} is twice the value of the odd mode impedance).

Odd Mode (Z_{oo}): the impedance seen when testing the impedance of one side of a pair of lines when the other is drive in equal and opposite polarity (half the value of the differential impedance).

Common mode (Z_{cm}): The impedance seen when testing into a pair of lines driven by identical (common) signals.

Even mode (Z_{oe}): The impedance measured testing one of a pair of lines which are driven by identical signals (Even mode is twice the common mode value).

When is it important to consider both odd and even mode impedance?

This is really a design issue and outside the normal scope of these notes; however, lets take one example — think again about noise on the signal pair considered above. Transmission lines need correct termination in order to preserve signal integrity and minimise reflections. In the case above, what is the correct termination? The signal will see the odd mode impedance, and the noise will see a higher impedance — the even mode. Should you choose the lower or higher, or a compromise value between the two? Or is there another solution?

Yes, there is a third solution; it is elegant and maybe not always necessary, however it is a method of terminating both the even and odd modes. First, simply terminate the two lines with the correct even mode value of terminating resistor to ground (let's call these two resistors R_a and R_b), and then add an additional resistor R_c between the pair (see Fig 2a).



Fig 2a Typical Pi termination for a coupled line pair

This resistor is invisible to the even mode signals as the even mode content on each track is identical so no even mode current flows in this resistor (Fig 2b).



Fig 2b Equivalent termination (showing R_c open circuit) in even mode

However, in odd mode the centre of the resistor will always be at 0v. Now this half of the resistor will appear in parallel with the even mode terminating resistor (Fig 2c). So the odd mode impedance is equal to $\frac{1}{2} R_c$ in parallel with R_a .

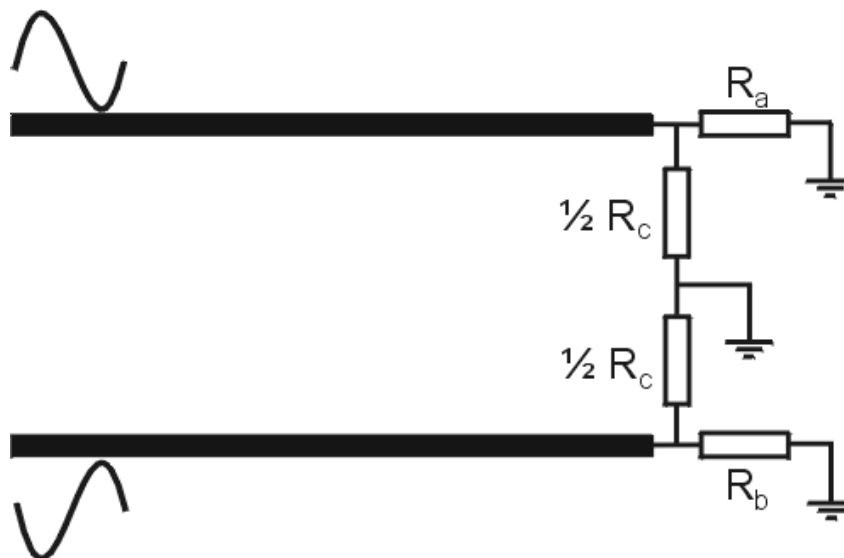


Fig 2c Equivalent termination (showing virtual ground) in odd mode

This arrangement offers perfect termination to signals propagating along the line in both odd and even modes.

The electric and magnetic fields for both modes are shown below.

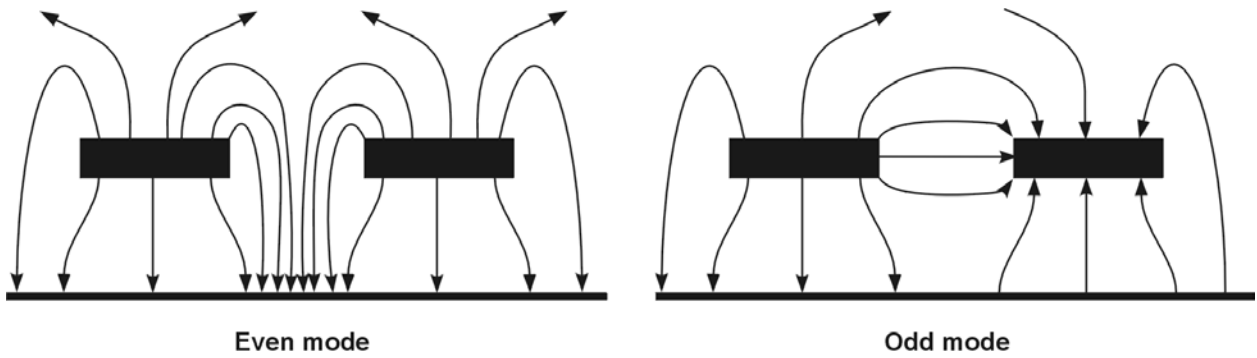


Fig 4a Electric fields in even and odd mode

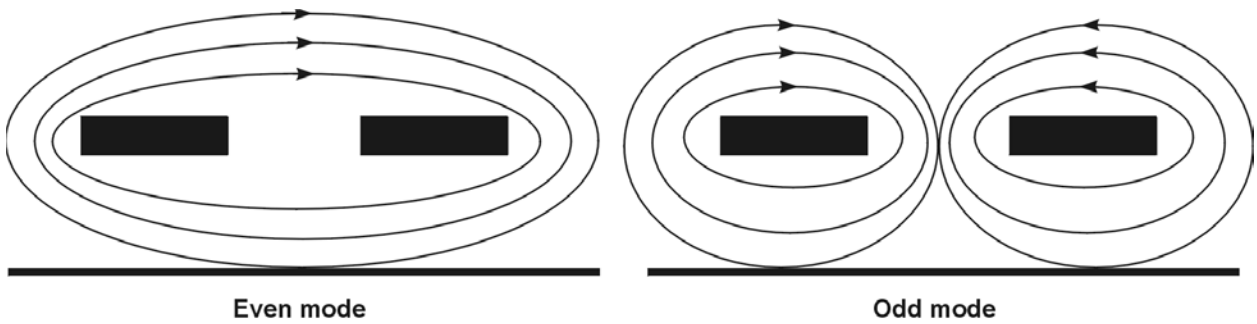


Fig 4b Magnetic fields in even and odd modes

In odd mode the equal and opposite polarity of the two propagating signals introduces a "virtual ground" plane between the traces.

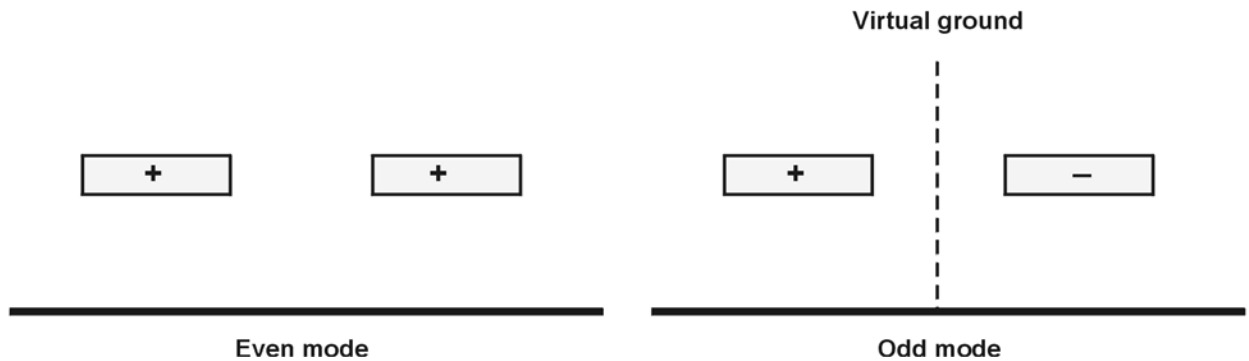


Fig 4c Virtual ground between traces in odd mode

How does this effect PCB fabrication?

An increasing number of designs (for example USB 2.0) call for control of both odd and even mode impedance; this means that more care needs to be taken when preparing data for impedance controlled PCBs. Now it becomes important to ensure that minor alterations to centre differential impedance values do not put the even mode out of spec, or vice versa. Polar Instruments' Si6000c uses powerful 2d field solvers to extract both odd and even mode impedance; these values may be rapidly extracted using the Si6000c Quicksolver model, or accessed directly through Microsoft Excel for an in depth graphical analysis of interrelationships between structure geometry and odd and even mode (see Fig 5 below).

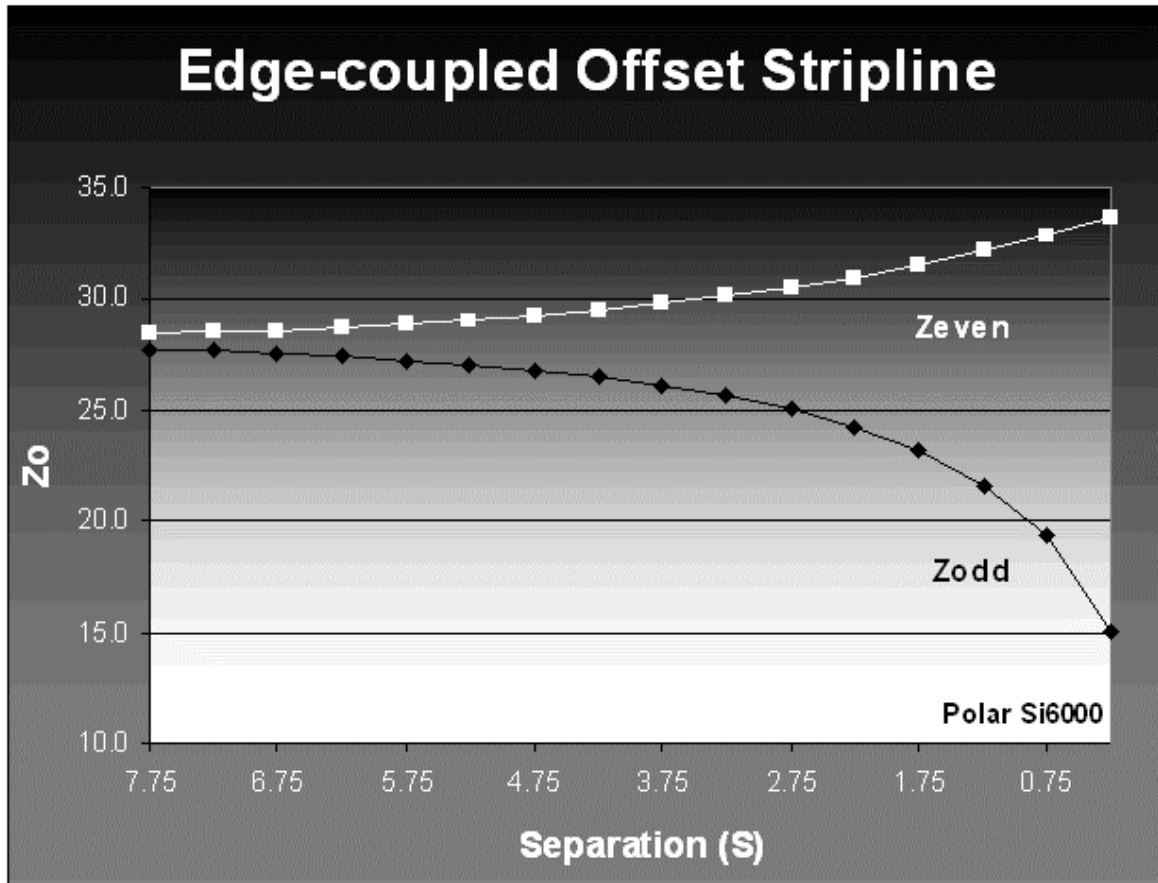


Fig 5 Odd and even mode impedance plotted against trace separation.

More information?

Further information on measuring PCB controlled impedances is available by email from martyn.gaudion@polarinstruments.com

For information on field solving impedance design software please contact: ken.taylor@polarinstruments.com

Further reading — if you would like a deeper understanding of some of the above you may find the following a good place to start:

Hall, Hall, McCall, *High-speed Digital Design*, Wiley, 2000

Howard Johnson and Martin Graham, *High Speed digital design: A handbook of Black Magic*, Prentice Hall 1993.



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