Adapted from notes by
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ECE 5317-6351
Microwave Engineering

Fall 2019

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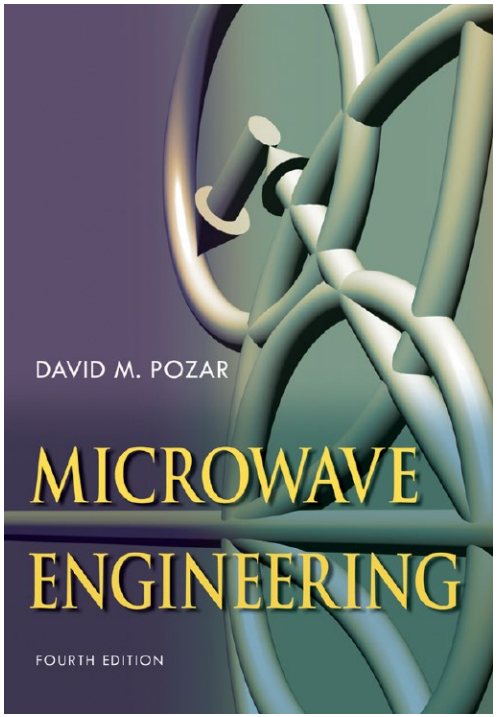
Dept. of ECE



Notes 4
Transmission Lines
Part 3: Baluns

Baluns

Baluns are used to connect coaxial cables to twin leads.

They suppress the <u>common mode</u> currents on the transmission lines.

Balun: "Balanced to "unbalanced"

Coaxial cable: an "unbalanced" transmission line

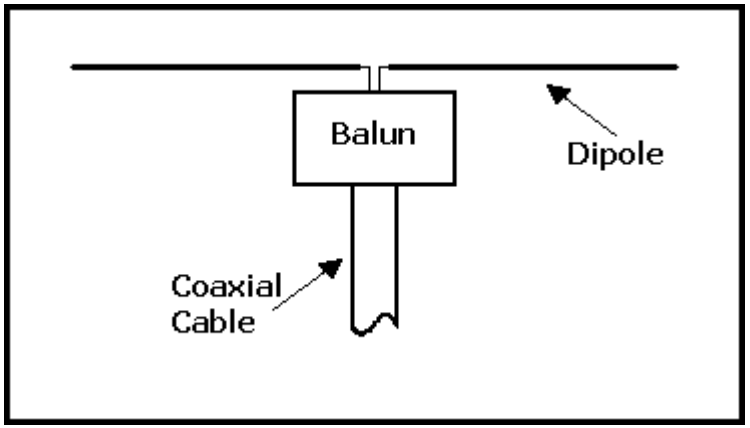
Twin lead: a "balanced" transmission line

4:1 impedance-transforming baluns, connecting 75Ω TV coax to 300Ω TV twin lead

https://en.wikipedia.org/wiki/Balun

Baluns (cont.)

Baluns are also used to connect coax (unbalanced line) to dipole antennas (balanced).

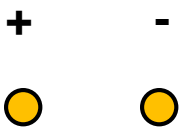


“Baluns are present in radars, transmitters, satellites, in every telephone network, and probably in most wireless network modem/routers used in homes.”

https://en.wikipedia.org/wiki/Balun

Baluns (cont.)

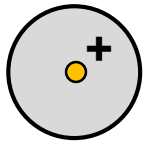
What does “balanced” and “unbalanced” mean?



Ground (zero volts)

Twin Lead

The voltages are usually *balanced* with respect to ground.



Ground (zero volts)

Coax

The voltages are usually *unbalanced* with respect to ground.

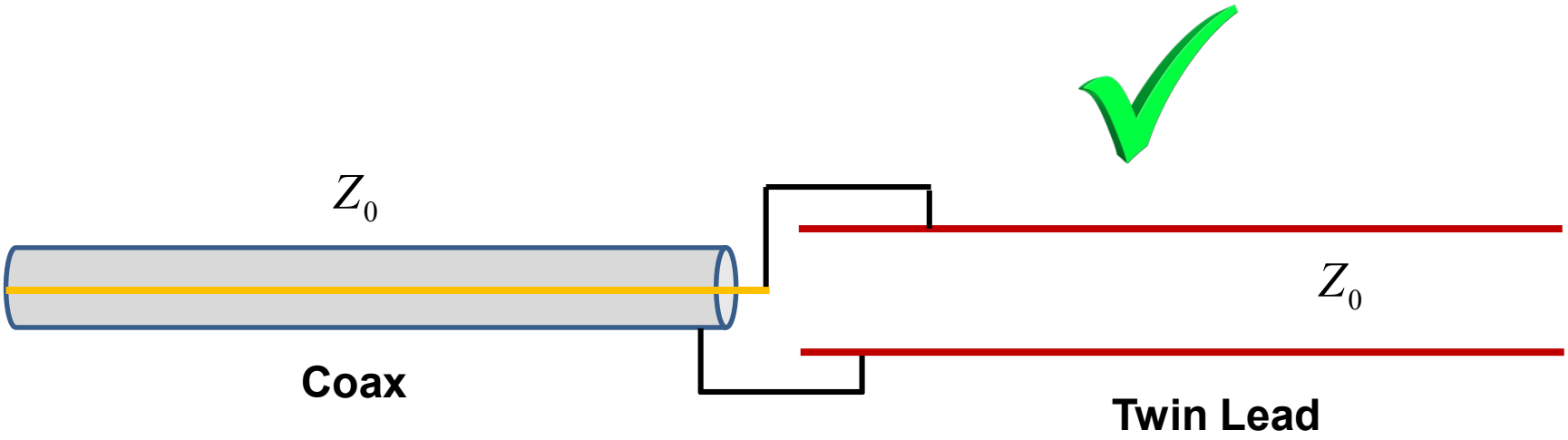
Note:
If the coax outer conductor was not at zero volts, there would be a field between the coax and the ground. There would be charge and current on the outside of the coax.
This would correspond to a “common mode”.

Baluns (cont.)

Baluns are necessary because, in practice, the two transmission lines are always both running over a *ground plane*.

If there were no ground plane, and you only had the two lines connected to each other, then a balun would not be necessary.

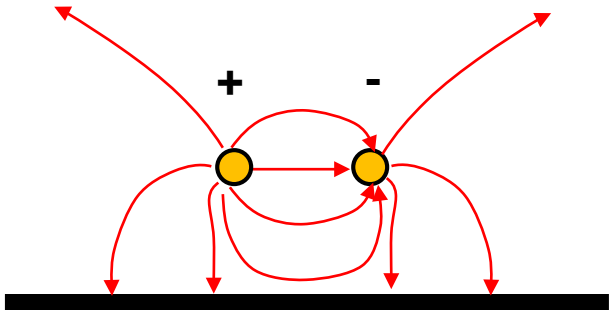
(But you would still want to have a matching network between the two lines if they have different characteristic impedances.)



No ground plane

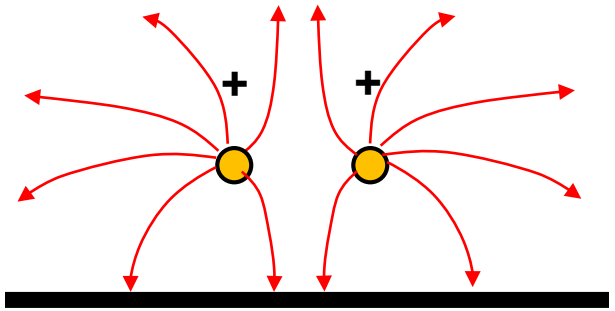
Baluns (cont.)

When a ground plane is present, we really have three conductors, forming a multiconductor transmission line, and this system supports two different modes.



Differential mode

(desired)



Common mode

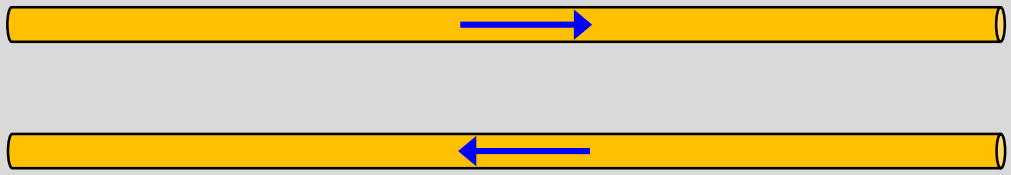
(undesired)

The differential and common modes are shown for a twin lead over ground.

For the common mode, both conductors of the transmission line act as one net conductor, while the ground plane acts as the other conductor (return path for the current).

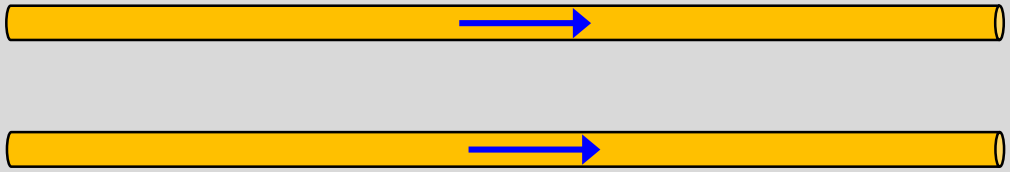
Baluns (cont.)

Differential mode: currents are equal and opposite



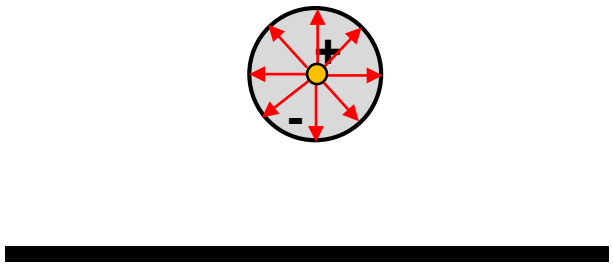
Ground

Common mode: a net current flows on the two conductors



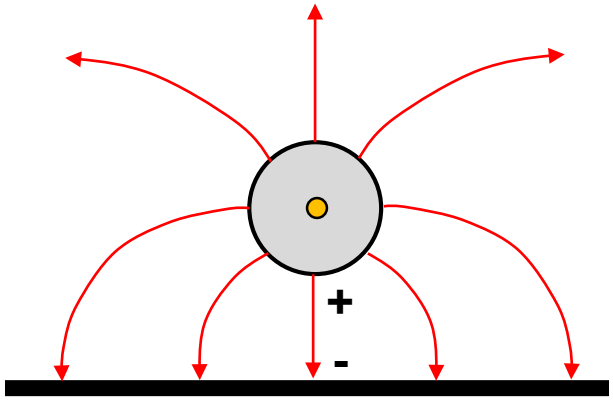
Ground

Baluns (cont.)



Differential mode

(desired)



Common mode

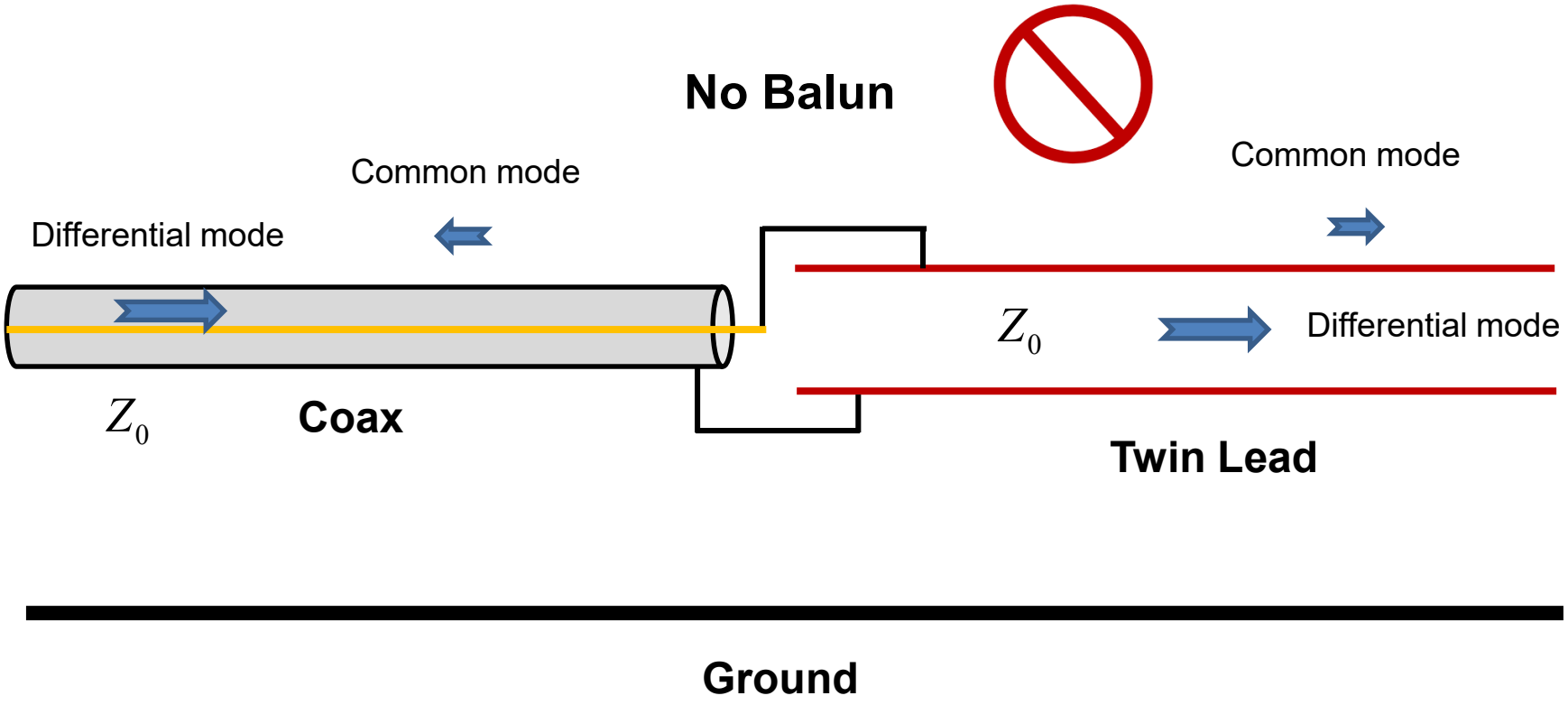
(undesired)

The differential and common modes are shown for a coax over ground.

(The red flux lines show the electric field.)

Baluns for Coax to Twin Lead

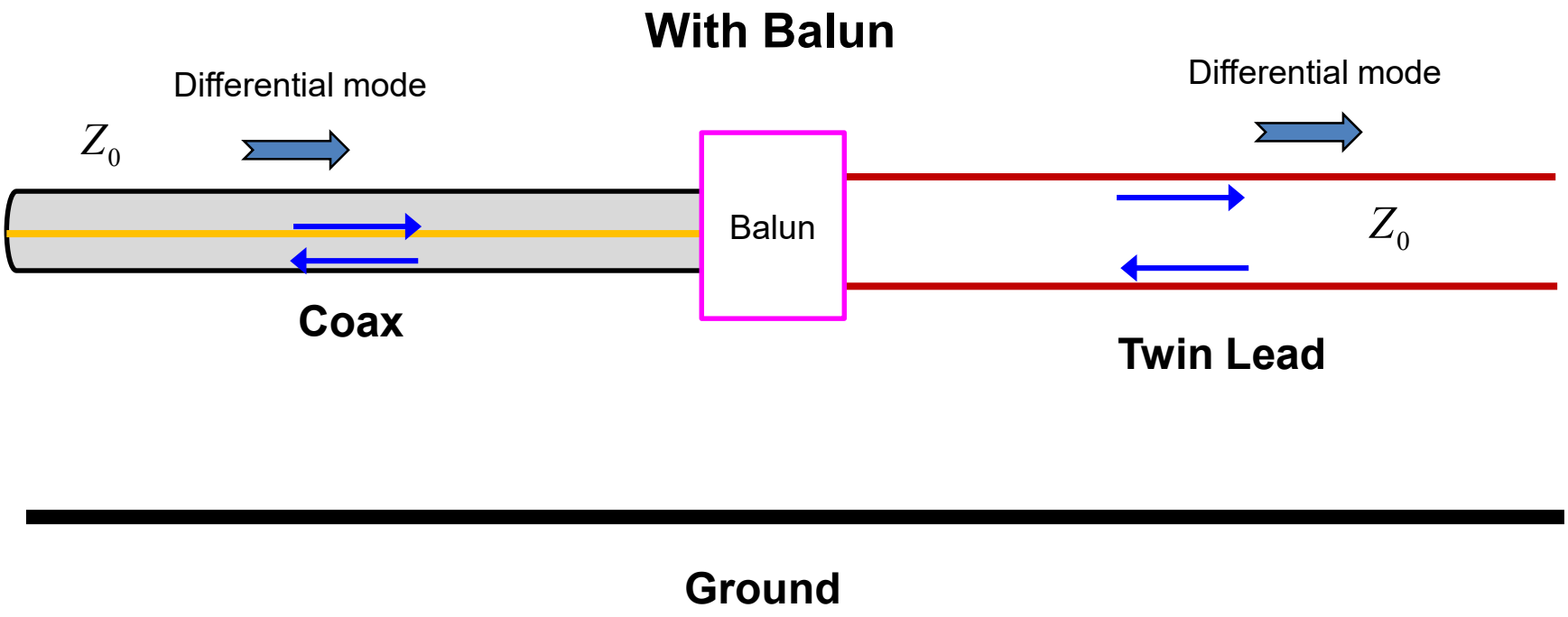
Because of the asymmetry, a common mode current will get excited at the junction between the two lines, and propagate away from the junction.



Note:
If the height above the ground plane goes to infinity, the characteristic impedance of the common mode goes to infinity, and there is no common mode current – we would not need a balun.

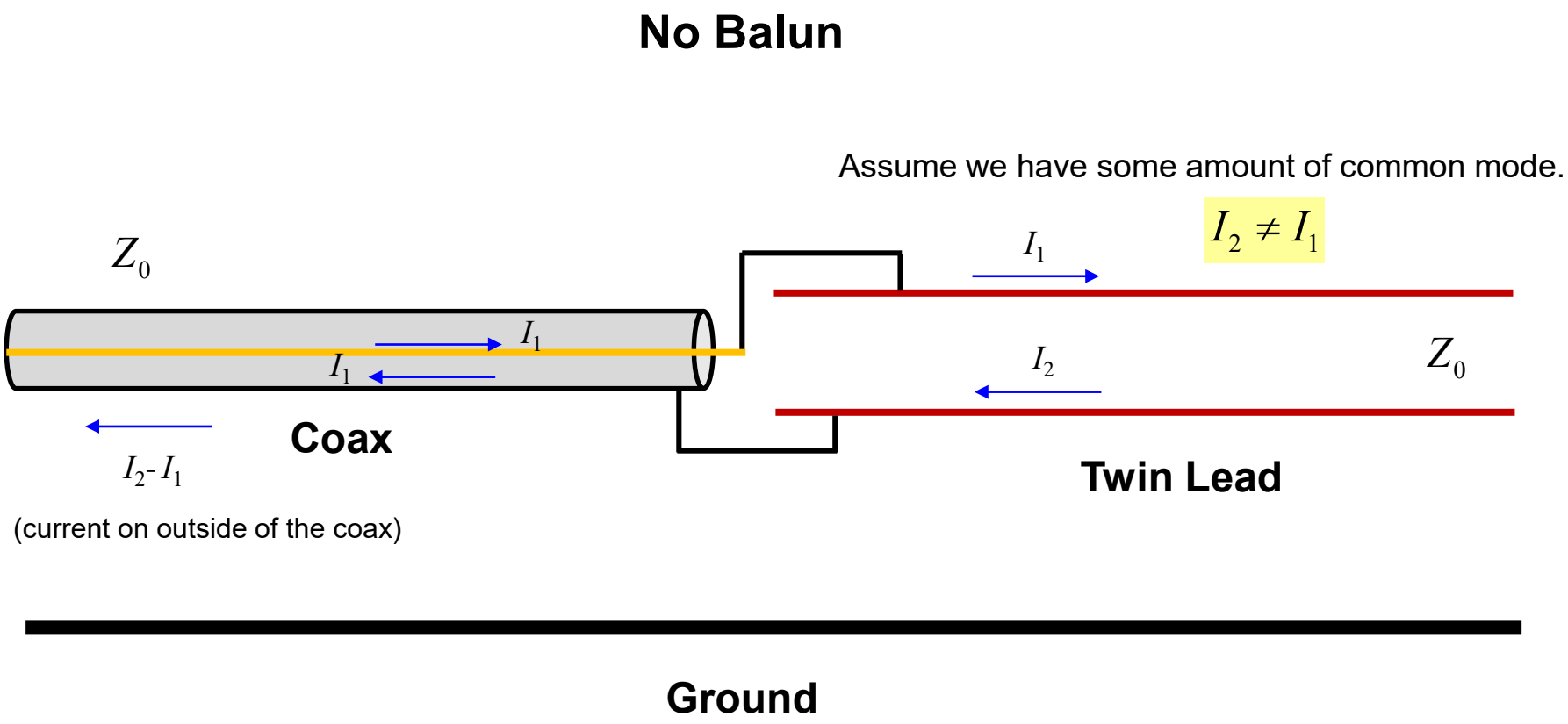
Baluns for Coax to Twin Lead (cont.)

A balun prevents common modes from being excited at the junction between a coax and a twin lead.



Baluns for Coax to Twin Lead (cont.)

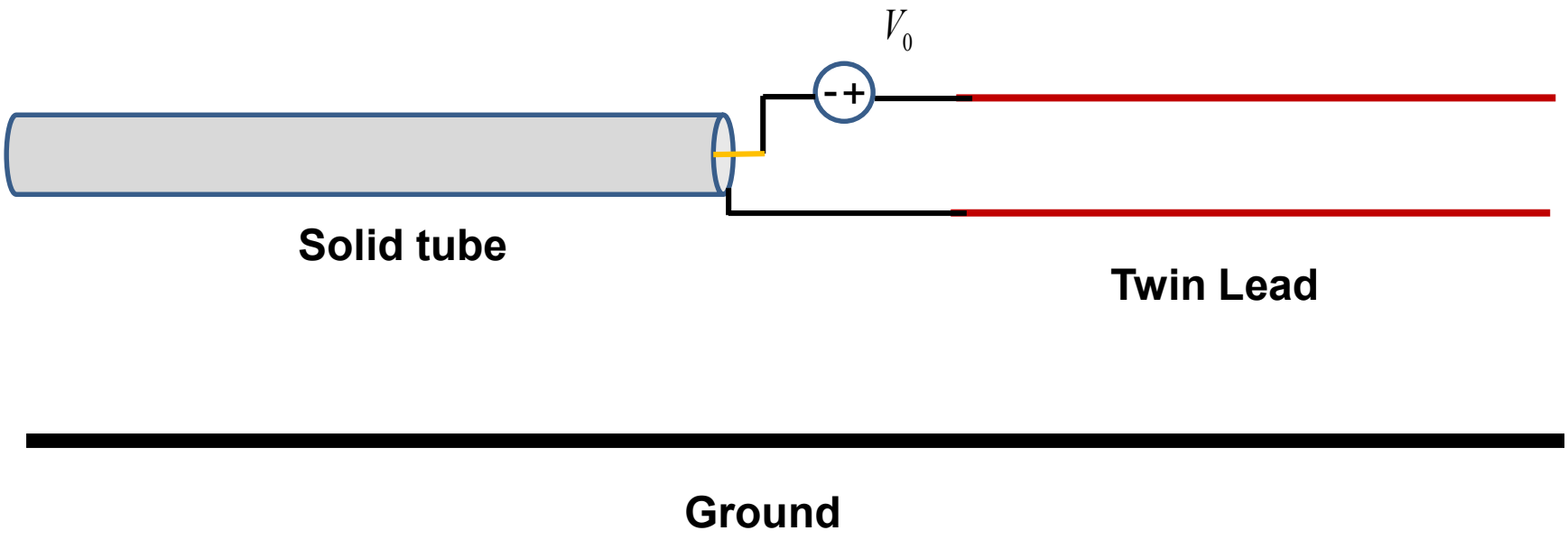
From another point of view, a balun prevents currents from flowing on the outside of the coax.



Baluns for Coax to Twin Lead (cont.)

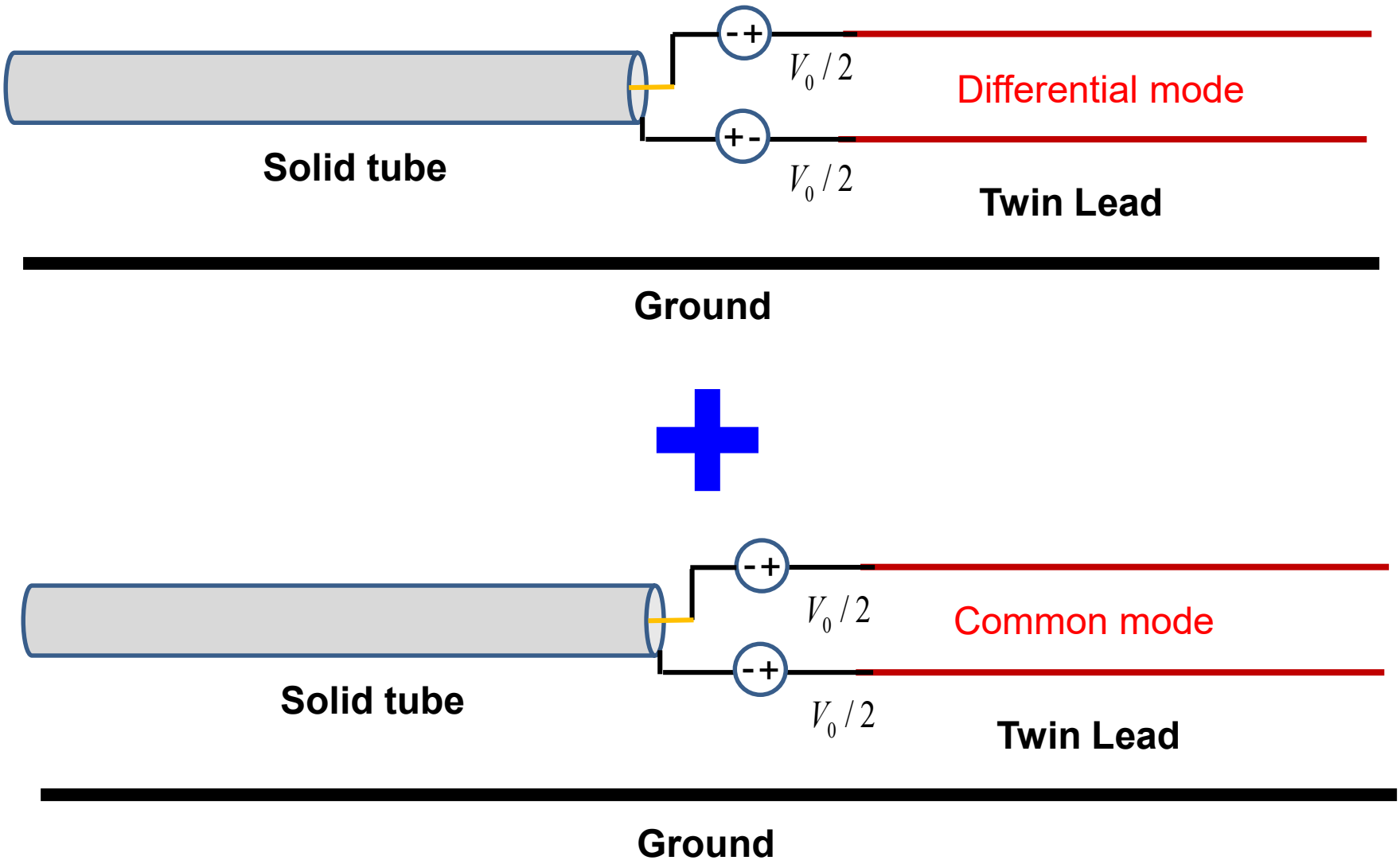
A simple model for the mode excitation at the junction

The coax is replaced by a solid tube with a voltage source at the end.



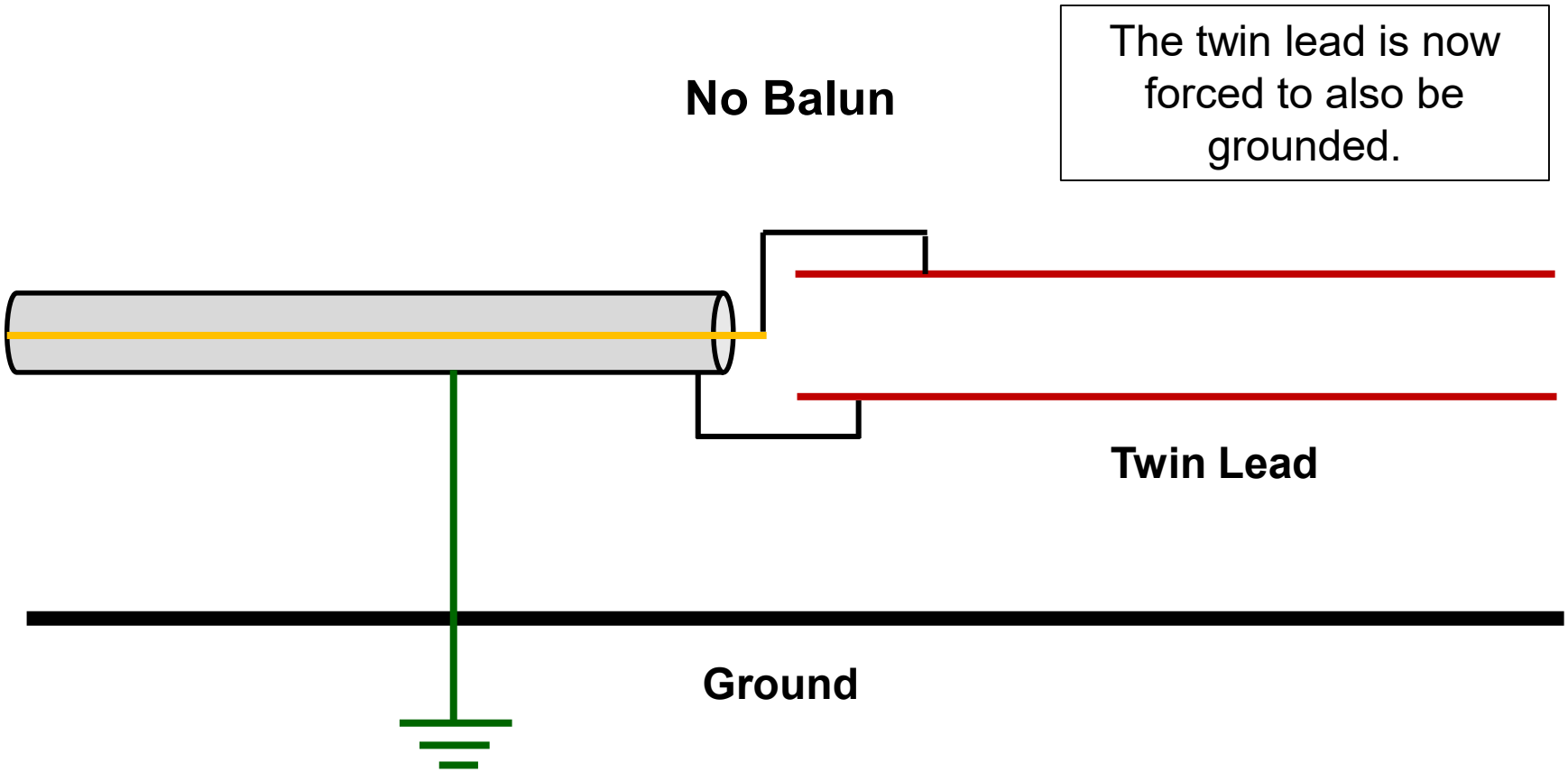
Baluns for Coax to Twin Lead (cont.)

Next, we use superposition.



Baluns and Grounding

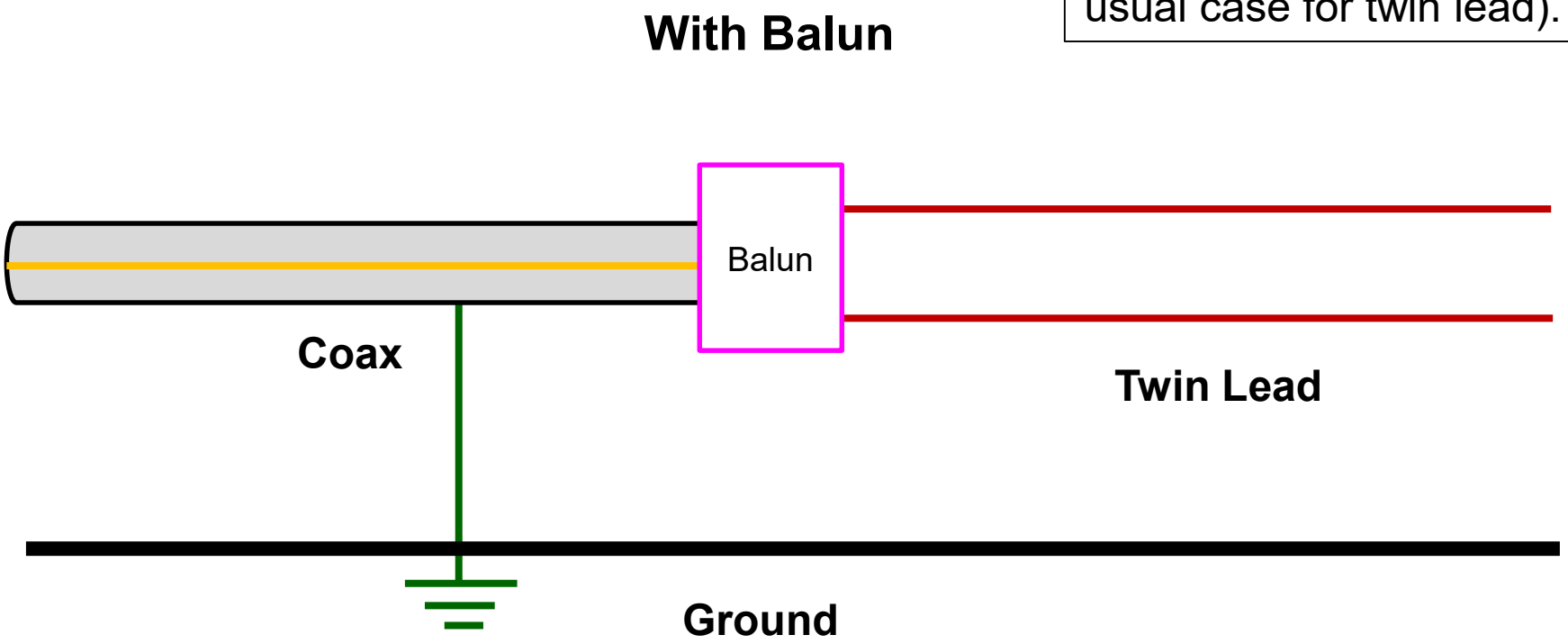
Baluns are also useful whenever one transmission line is grounded and the other one isn't.



Baluns and Grounding (cont.)

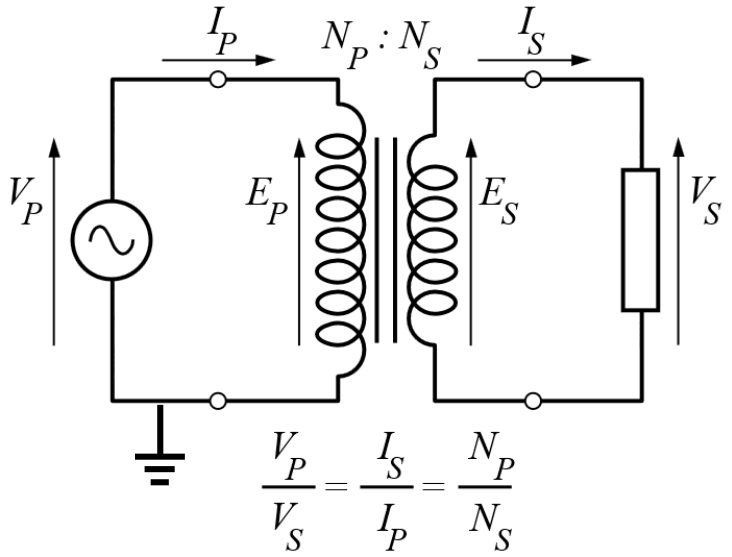
Baluns are also useful whenever one transmission line is grounded and the other one isn't.

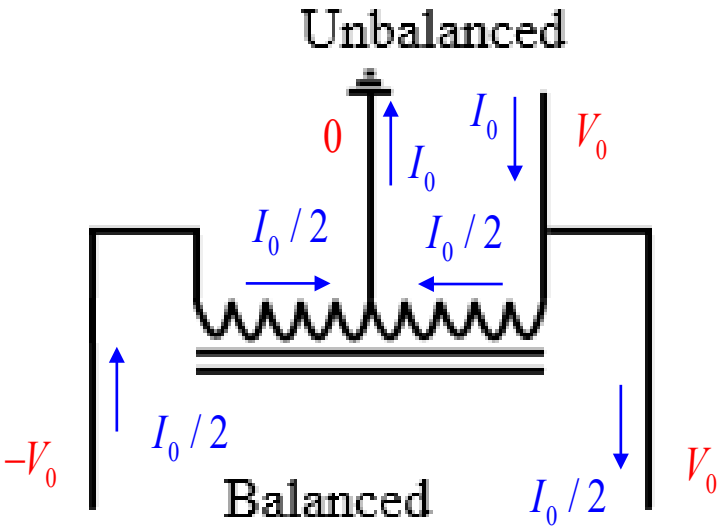
The twin lead is now ungrounded (this is the usual case for twin lead).



Baluns using Transformers

One type of balun uses an isolation transformer.





- The input and output are isolated from each other, so the input can be grounded if desired (e.g., when using a coax feed for the primary) while the output is not (e.g., when using a twin lead feed for the secondary).
- The common mode must be zero at the transformer, since a net current cannot flow off of the windings into the transformer core.
- This balun uses a 4:1 autotransformer, having three taps on a single winding, on a ferrite rod.
- The center tap on the input can be grounded if desired, while the balanced output is not. The common mode is choked off due to the high impedance of the coil.

https://en.wikipedia.org/wiki/Balun

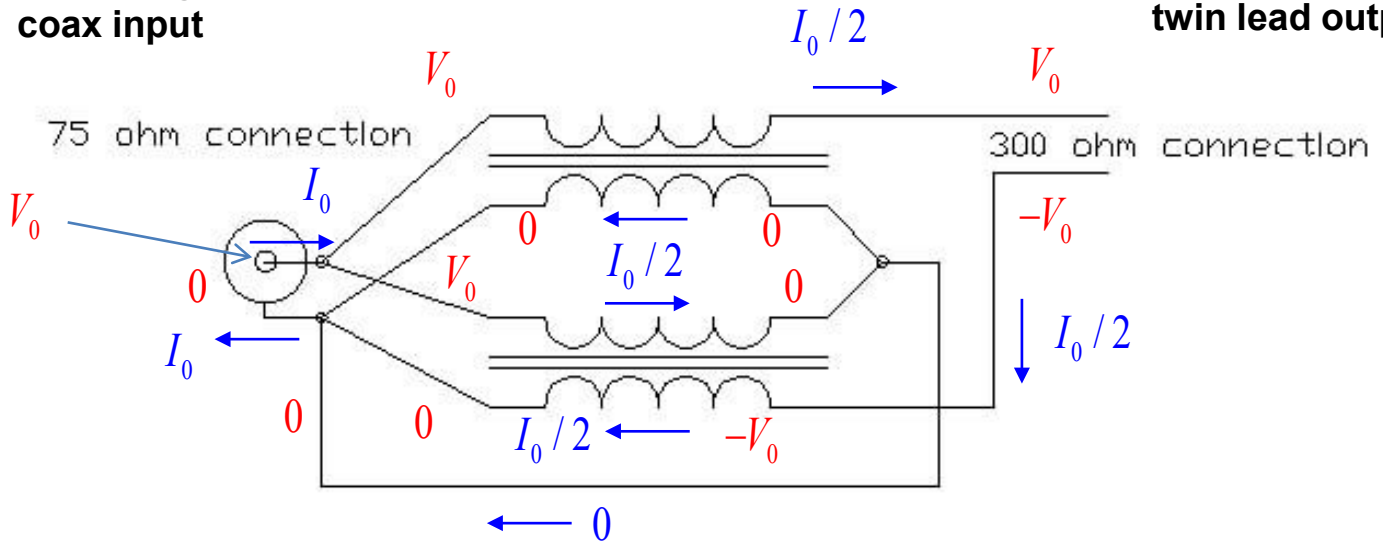
Baluns using Transformers (cont.)

Here is a more exotic type of 4:1 impedance transforming balun.

"Guanella balun"

Unbalanced and grounded coax input

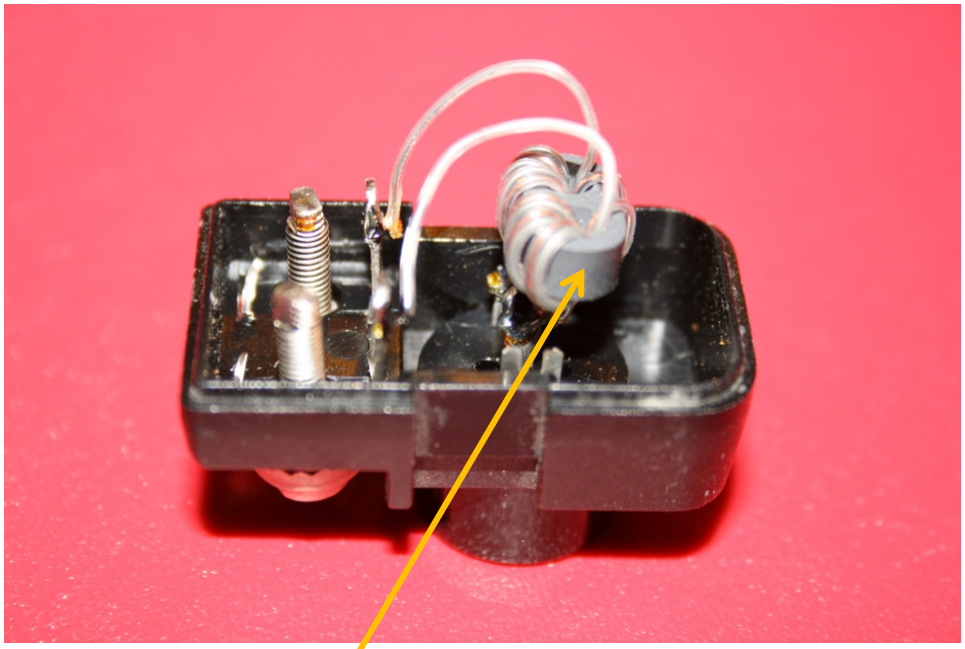
Balanced and ungrounded twin lead output



This balun uses <u>two</u> 1:1 transformers to achieve symmetric (and ungrounded) output voltages.

Baluns using Transformers (cont.)

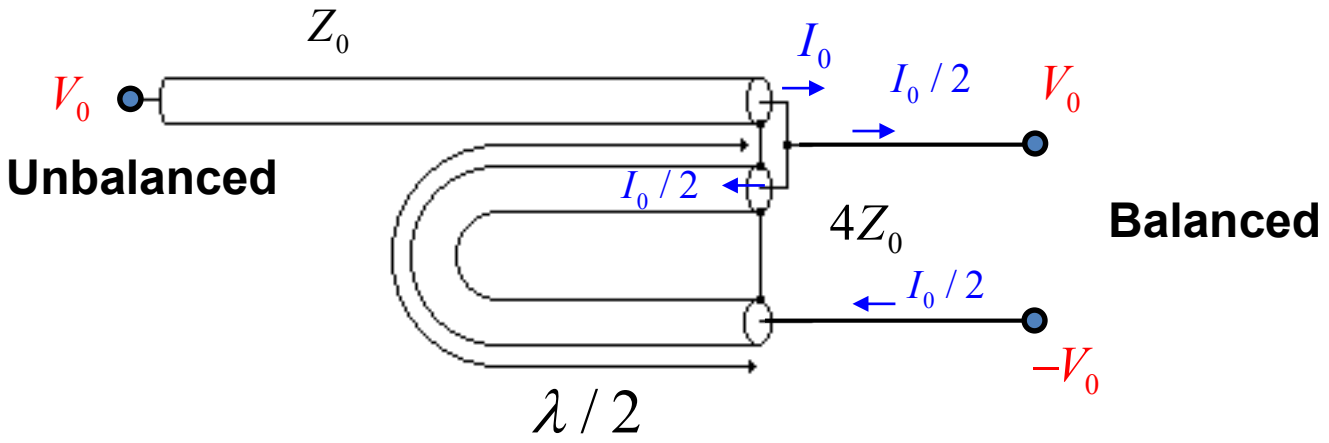
Inside of 4:1 impedance transforming VHF/UHF balun for TV



Ferrite core

Balun using Coax

A 4:1 impedance transforming balun built using only coax



The two outputs are 180^o out of phase.

(See slide 24 for a microstrip version.)

Choke Baluns

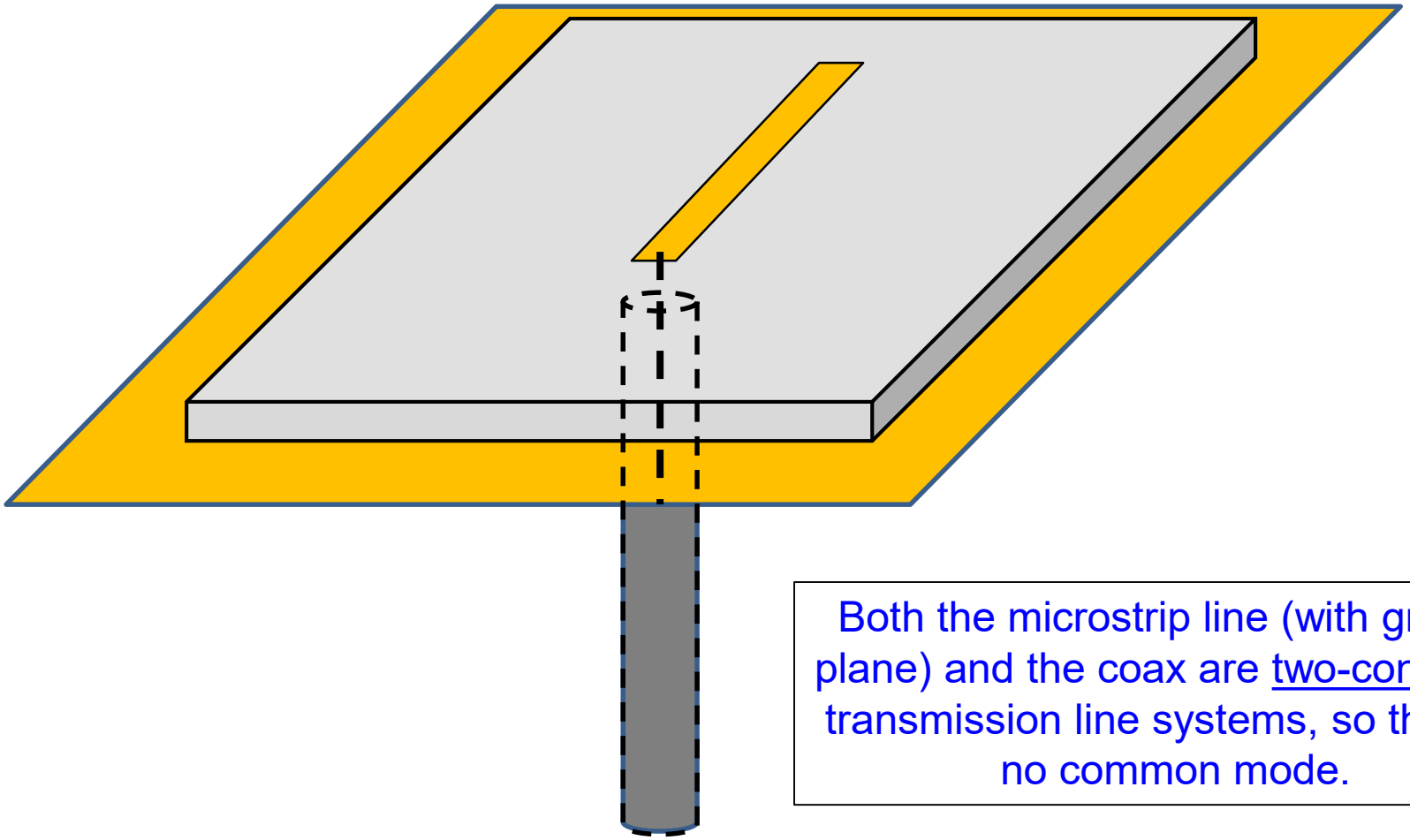
Another type of balun uses a choke to “choke off” the common mode.

A coax is wound around a ferrite core. This creates a large inductance for the common mode, while it does not affect the differential mode (whose fields are confined inside the coax).

https://en.wikipedia.org/wiki/Balun

Microstrip Line

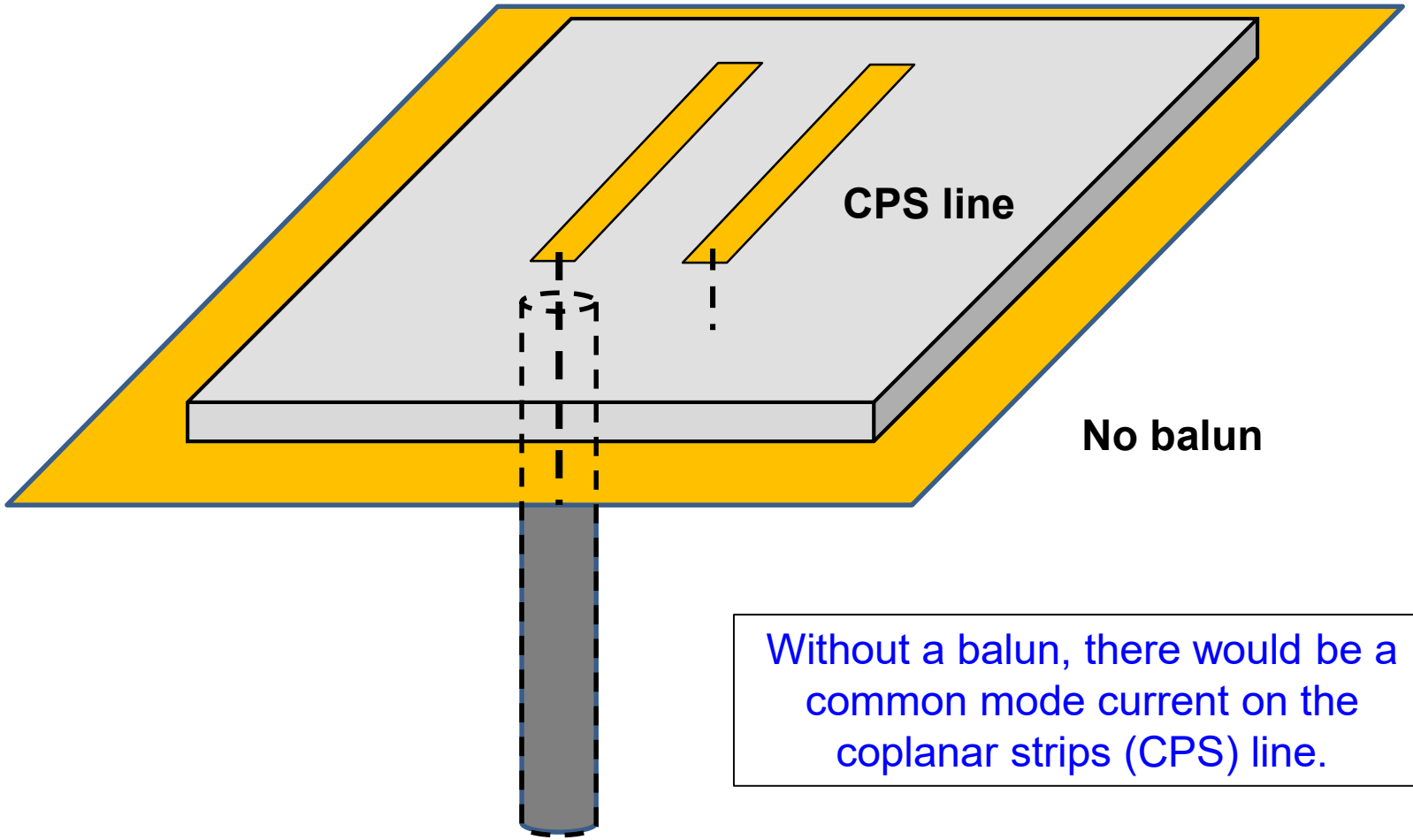
Coax can be used to feed a microstrip line on a PCB without needing a balun.



Both the microstrip line (with ground plane) and the coax are two-conductor transmission line systems, so there is no common mode.

Baluns and CPS Line

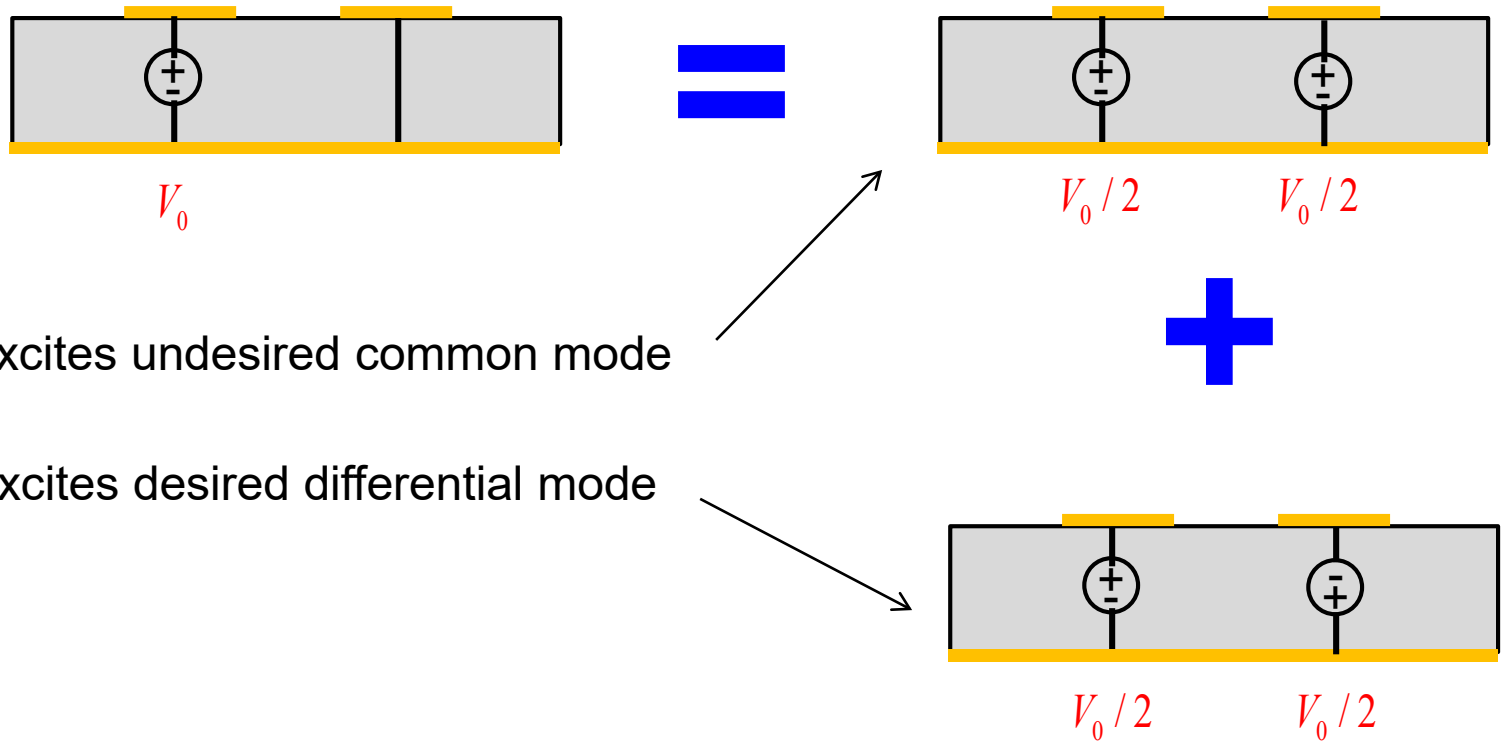
Baluns are very useful for feeding differential circuits with coax on PCBs.



Without a balun, there would be a common mode current on the coplanar strips (CPS) line.

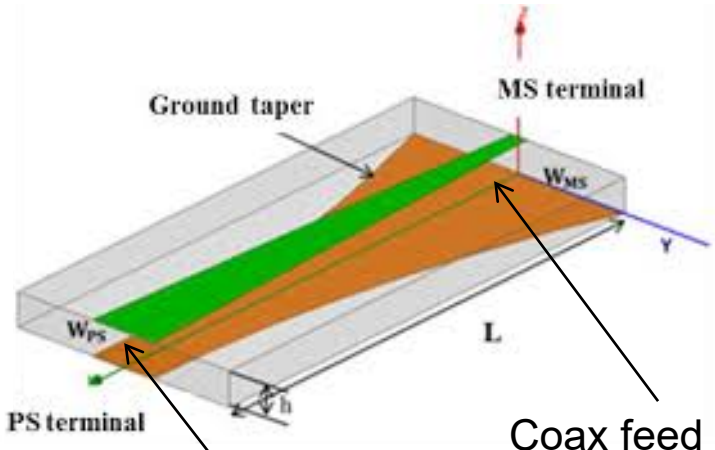
Baluns and CPS Line (cont.)

Superposition allows us to see what the problem is.

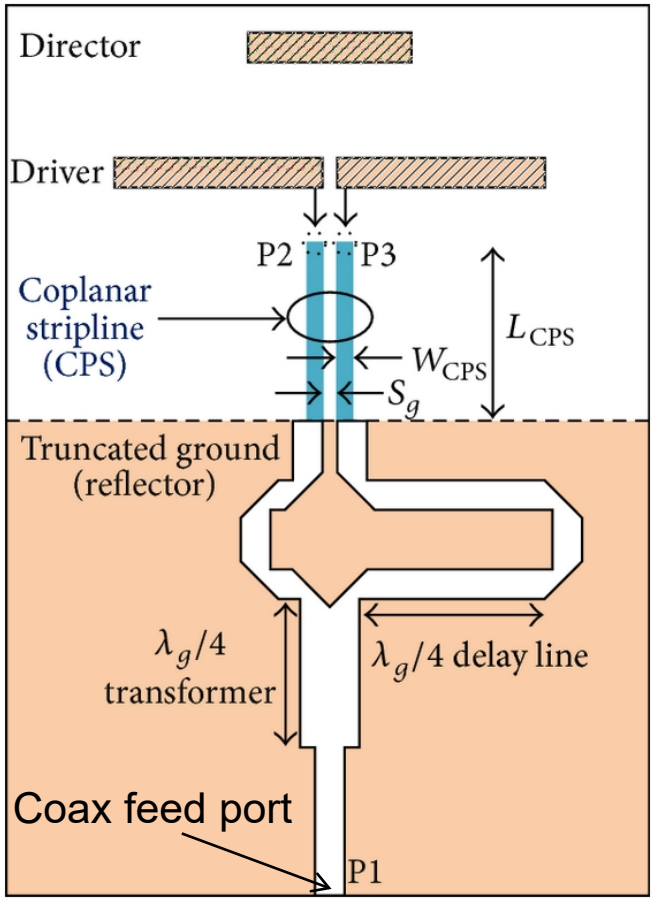


Baluns and CPS Line (cont.)

Baluns for CPS can be implemented in microstrip form.



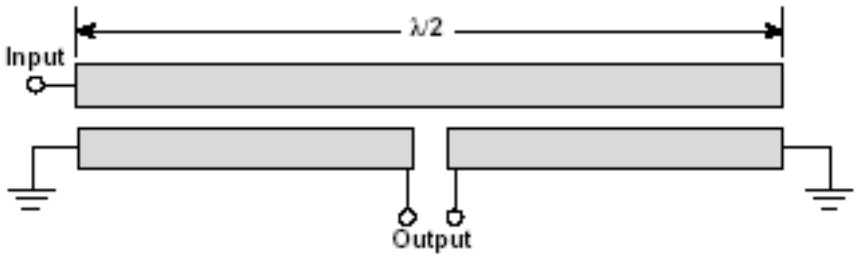
Tapered balun



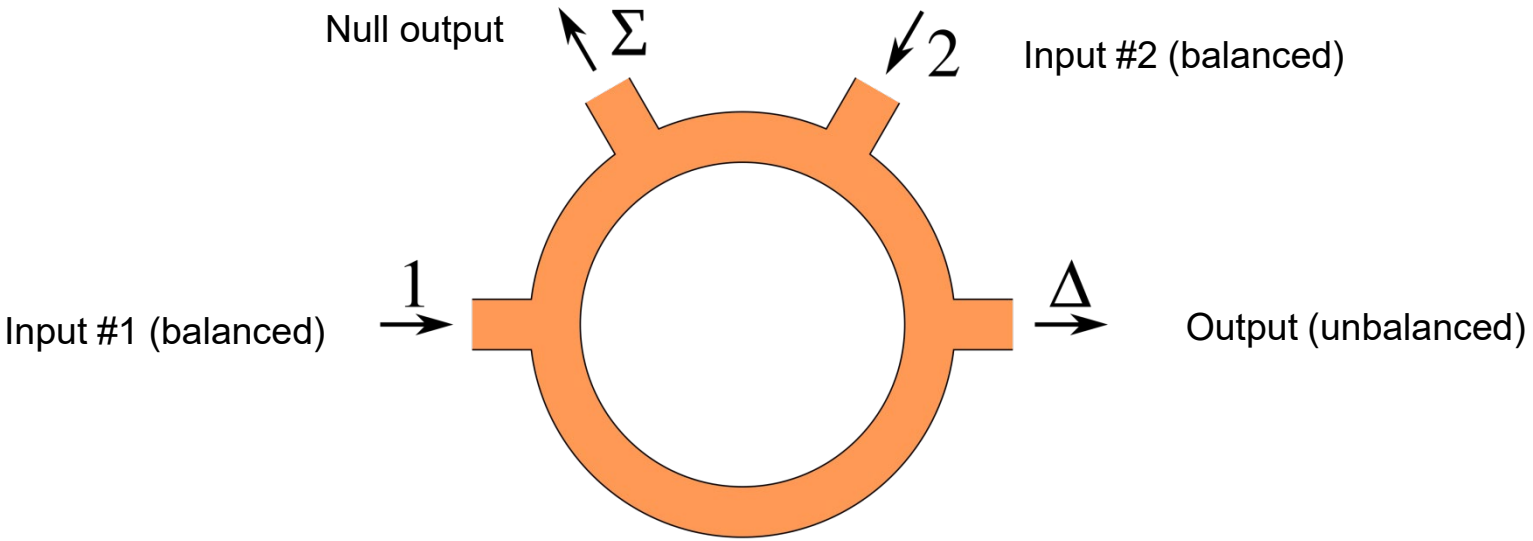
Balun feeding a microstrip Yagi-Uda antenna

Baluns and CPS Line (cont.)

Baluns for CPS can be implemented in other microstrip forms.



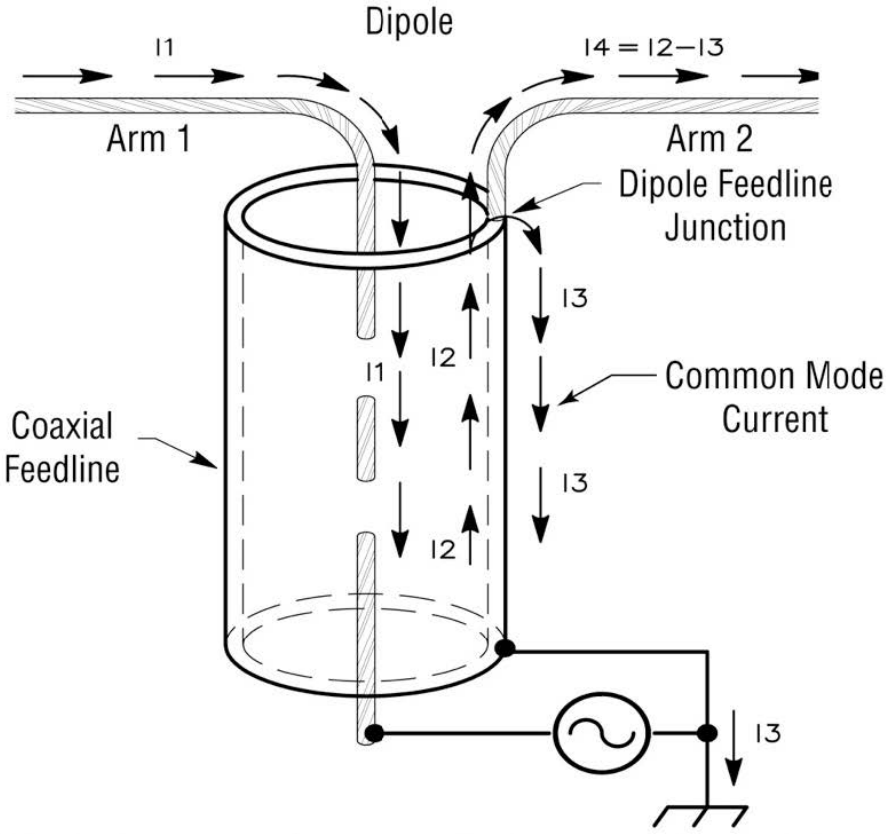
Marchand balun



180° hybrid rat-race coupler used as a balun

Baluns for Antennas

If you try to feed a dipole antenna directly with coax, there will be a common mode current on the coax.



$I_1 = I_2$

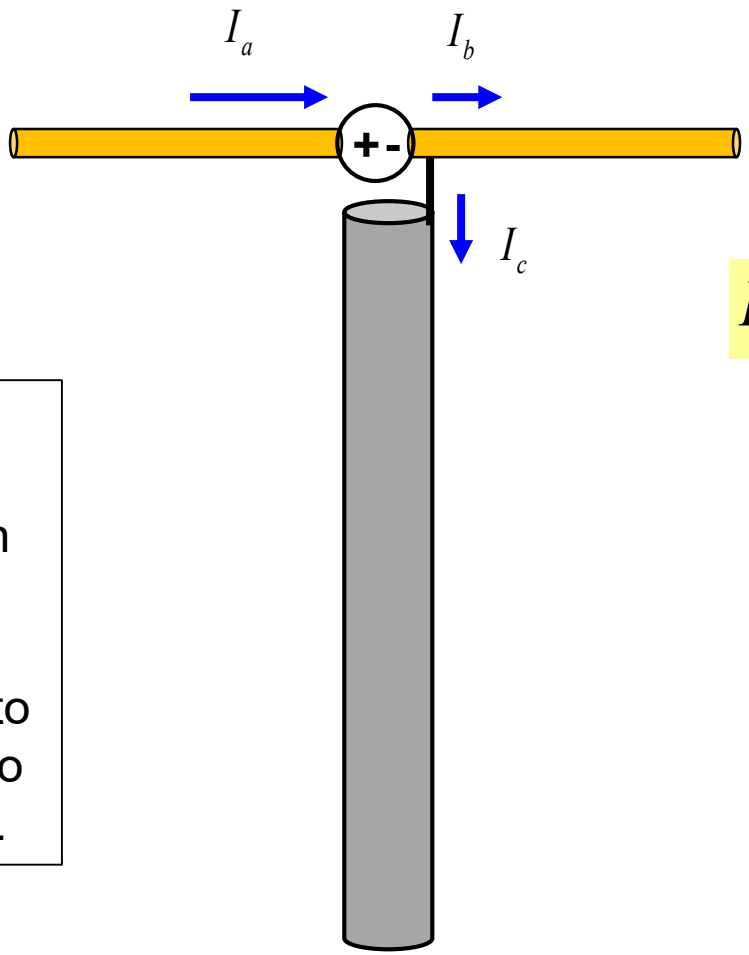
$I_3 \neq 0$

$I_4 \neq I_1$

No balun

Baluns for Antennas (cont.)

The equivalent circuit explains why there is a common mode on the coax.



$$I_a = I_b + I_c$$

$$I_a \neq I_b$$

No balun

Note:
The voltage source sees an asymmetric structure. The current flowing to the right has two possible paths.

Baluns for Antennas (cont.)

Baluns are commonly used to feed dipole antennas from coax.

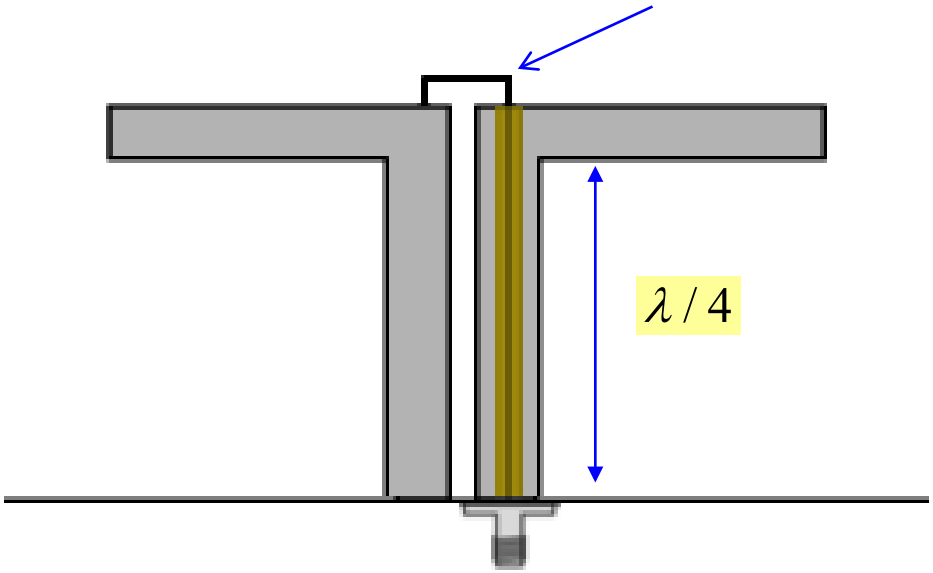
A balun first converts the coax to a twin lead, and then the twin lead feeds the dipole.

Baluns for Antennas (cont.)

Baluns are commonly used to feed dipole antennas from coax.

"Twin Arm Balun"

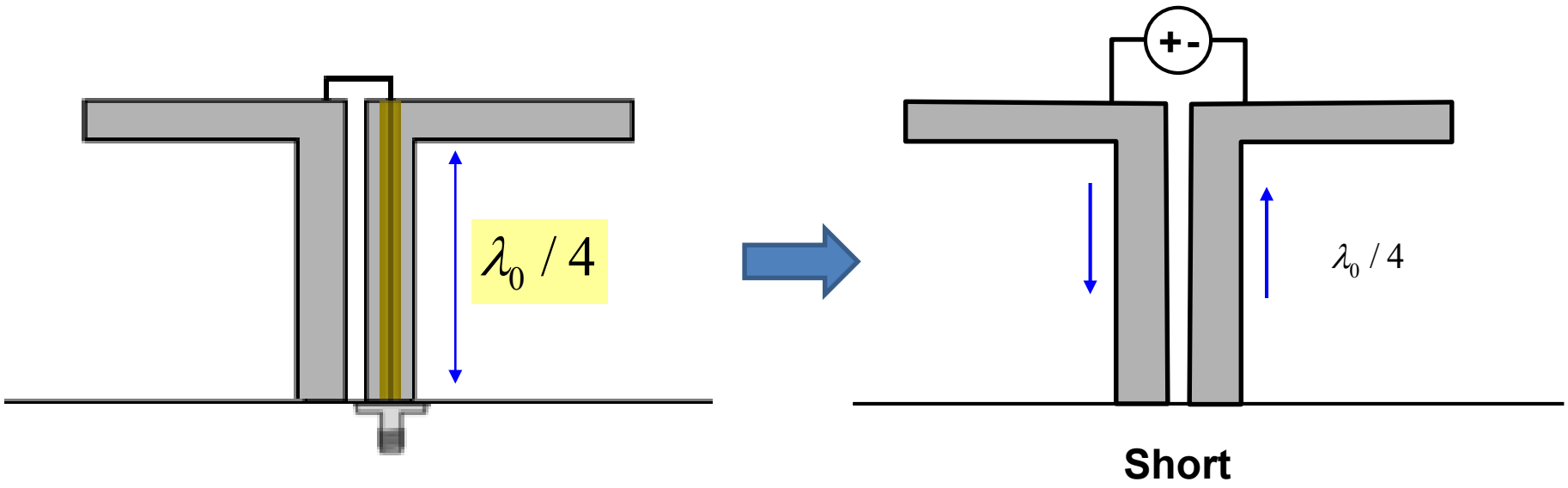
This acts like voltage source for the dipole, which forces the differential mode.



The dipole is loaded by a short-circuited section of "twin lead" (composed of the two hollow pipes). This is an open circuit at the source location because of the $\lambda/4$ height.

Baluns for Antennas (cont.)

Equivalent Circuit

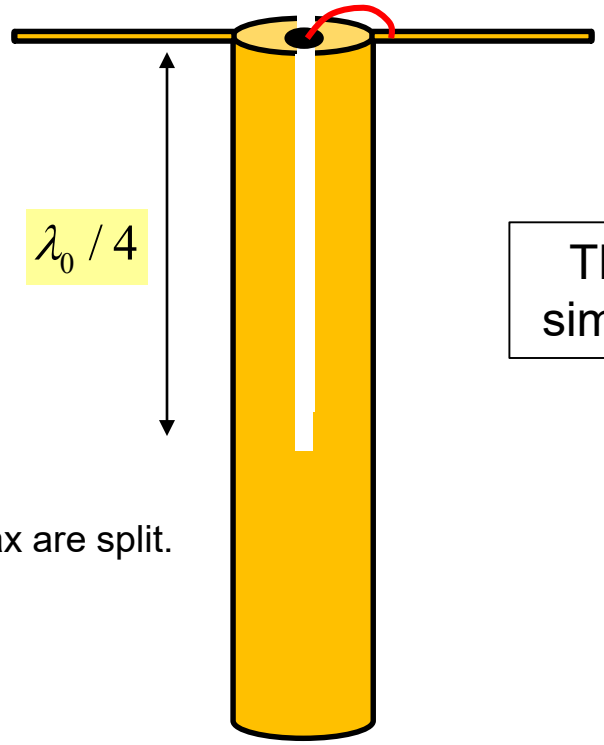


- The equivalent circuit shows us that the current on the dipole arms are perfectly balanced.
- The voltage source sees the dipole in parallel with a short-circuited length of “twin lead” (made from the vertical pipes) of length $\lambda_0 / 4$.

Baluns for Antennas (cont.)

Another balun for feeding a dipole antenna from coax.

"Split Coax Balun"



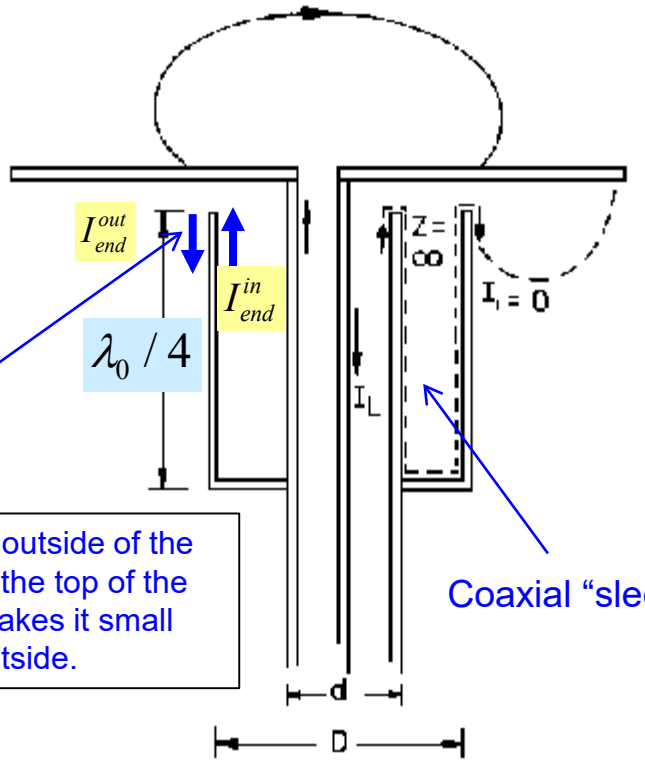
Both sides of the coax are split.

The operation here is very similar to the previous balun.

Baluns for Antennas (cont.)

Another balun for feeding a dipole antenna from coax.

"Bazooka Balun"



$$I_{end}^{in} = 0 \quad (\lambda_0 / 4)$$

$$I_{end}^{in} = I_{end}^{out} \quad (\text{KCL})$$

$$\Rightarrow \quad I_{end}^{out} = 0$$

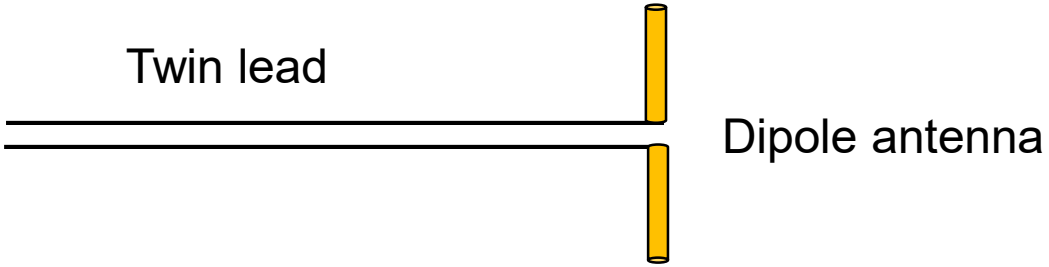
The current on the inside and outside of the sleeve is forced to be zero at the top of the sleeve (open circuit). This makes it small everywhere on the outside.

Coaxial "sleeve" region

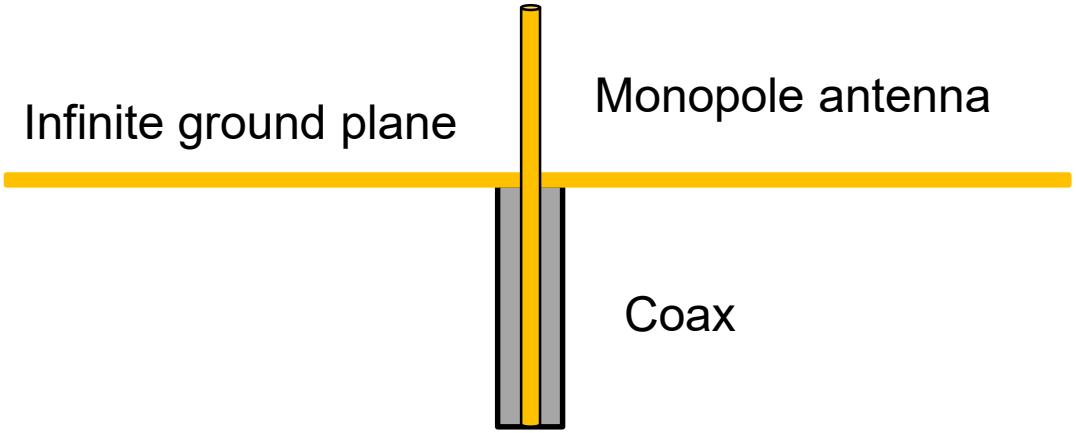
A "sleeve balun" directly connects a coax to a dipole.

Baluns for Antennas (cont.)

A balun is not always necessary when feeding an antenna.



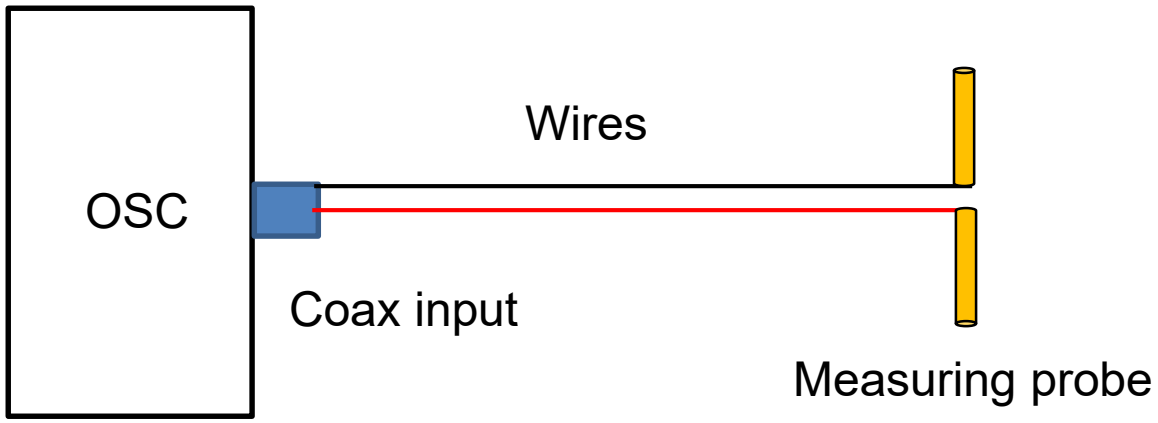
The system stays balanced – no common mode.



Current cannot flow on the outside of the coax.

Baluns and Measuring Probes

Baluns can be important when connecting to unbalanced devices like oscilloscopes.

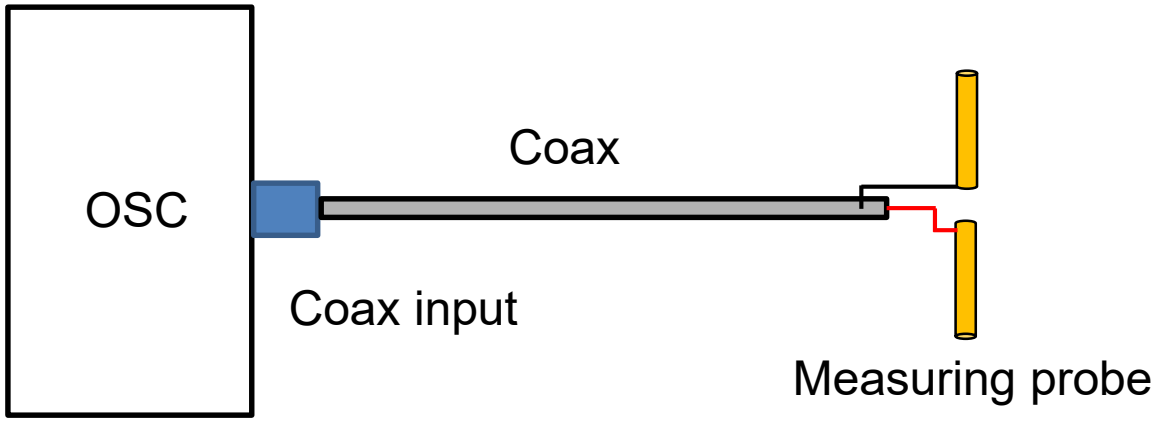


No Balun

There may be a strong common mode current on the two coax wires. The coax wires will act as an antenna! You may not really be measuring the field from the probe.

Baluns and Measuring Probes (cont.)

Baluns can be important when connecting to unbalanced devices like oscilloscopes.

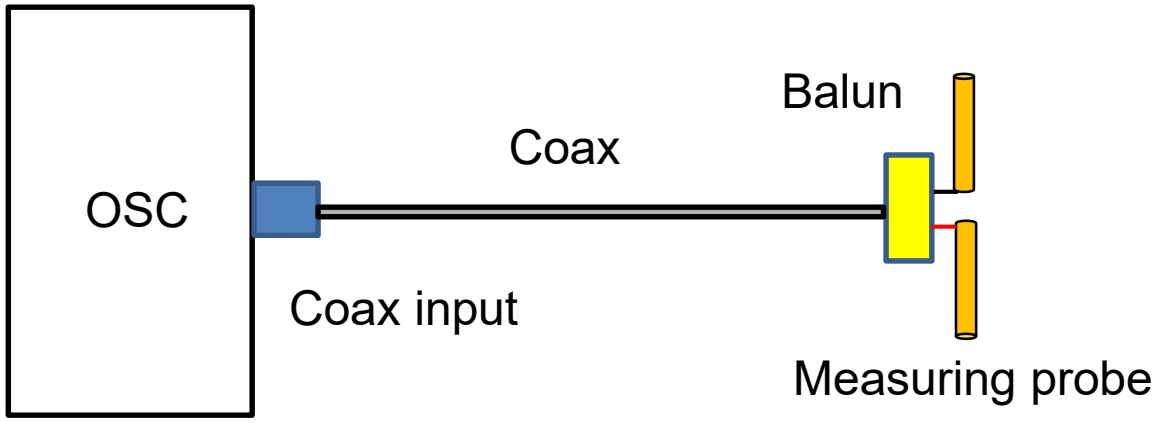


No Balun

Now there is a common mode on the coax. The coax will act as an antenna! You may not really be measuring the field from the probe.

Baluns and Measuring Probes (cont.)

Baluns can be important when connecting to unbalanced devices like oscilloscopes.



With Balun

Now there is only a differential mode on the coax, and the coax acts as a transmission line. We measure what is coming from the probe.