Common modes and cable traps

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Purpose: Cable traps are a particular class of balun, designed to restrict current flow on the outside of coaxial cable. Current on the outside of a coaxial cable produces unwanted effects such as radiation, sensitivity to external interference and probe sensitivity to cable positioning [1]. This problem becomes significantly worse as frequency increases. Cable traps block current on the outside of the coaxial cable and make the probe insensitive to different cable loading conditions. The aims of this study are to review wave propagation in coaxial cable, to describe three common designs of cable traps (ferrite, tank circuit and bazooka), and to present a simple method for measuring trap effectiveness.

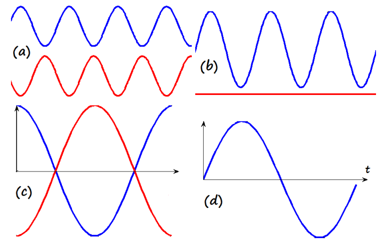

Figure 1 *Balanced (a), unbalanced (b) propagation mode, differential mode (c) and common mode (d).*

Outline of content: Transmission lines convey electromagnetic energy from one point to another. Transmission lines can be separated into two types: balanced and unbalanced. The former uses two conductors of equal impedance, such as a twisted pair (fig. 1a). The latter uses two conductors with unequal impedances, one of which is considered as ground, such as coaxial cable (fig. 1b). There are also two different modes of signal propagation: differential mode (DM) and common mode (CM). The DM signal is carried by both conductors with the same amplitude but 180° phase difference (fig. 1c). There is a voltage difference between the two lines with current flowing in opposite directions in the two conductors. The CM signal is carried when current from both lines flows in the same direction (fig. 1d). No current flows between these two lines because the voltage difference between them is zero. The DM is the "wanted" mode which carries the information, while the CM signal is generally "unwanted". When considering RF probes for magnetic resonance, the unbalanced part is typically a coaxial cable, while the balanced part is the feed to the RF probe itself (loop, microstrip, birdcage, etc.). Coaxial cable consists of three conducting surfaces: the inner conductor, and the inner and outer surfaces of the outer conductor, which are separated from each other due to the skin effect (fig. 2). Assuming a perfect shield, the inner surface of the outer conductor and inner conductor couple strongly, forming a 1:1 transformer resulting in currents of equal magnitude and opposite direction on the two surfaces. DM signals are thus transmitted along coaxial cable as a TEM wave between these two surfaces [2]. In this case the outer conductor of the coaxial cable carries no current. The inside of the coaxial cable cannot support CM signals (due to the strong coupling), forcing the common mode currents to travel on the outside of the outer conductor (i.e. on the outside of the coaxial cable). This feature of coaxial cable makes it particularly easy to suppress common-mode signals using cable traps. The presence of common modes may be observed by the "hand effect" – moving ones hand along the probe cable changes the resonance frequency and/or match of the probe. If a probe is sensitive to CM currents, the outer shield of the feeding cable (and anything coupled to it) becomes part of the resonant circuit. Thus, the coil resonance becomes sensitive to cable environment changes. Three origins for the common mode signal can be identified: it can be created via external radiation, by electromagnetic coupling between the outer coaxial cable shield and the local magnetic field produced by the probe, and at the cable-probe interface where the two surfaces of the coaxial cable outer are no longer separated. Currents on the outside of the cable create additional losses (dielectric and radiation), and can cause serious burns to the patient. We now consider three common trap designs. A ferrite trap is formed by a ferrite core placed around a coaxial cable. The core increases the CM impedance of the cable, blocking CM current flow (fig. 3a). It is broadband and very useful for bench testing, but cannot be used near the scanner as the ferrite is extremely magnetic and saturates in the static field. A tank trap is formed by making a small number of loops of coaxial cable, creating an inductance with the outer part of the shield, and resonating this with a parallel capacitor (fig. 3b). The high impedance produced at the resonant frequency again blocks CM currents. The bazooka balun is similar to the tank trap, but uses a quarter-wave transmission line section, short circuited to the cable outer at one end, creating a high impedance at the opposite end (figure 3c). As the length of the bazooka depends on the desired blocking frequency, this design becomes more practical at higher field. It can be further shortened using either a high permittivity material between the cable outer and the quarter-wave section, or by capacitors to the open-circuited end. To detect current transmission on the outside of a coaxial cable, a pair of 'current clamps' can be used [3]. These are made from a sniffer loop, coupled to the cable outer using a ferrite core, which forms a 1:1 transformer between the cable outer and the sniffer loop. Using commonly available split-core ferrites, this transformer can easily be clipped around the cable under test (fig. 4). Current flowing on the outside of the shield induces, through the ferrite core, a current in the sniffer loop, providing measurement of the common modes. One probe is used to inject signal onto the cable outer, while a second probe is used to detect the transmitted common mode signal, typically measured as S_{21} using a network analyzer. By moving the pickup clamp along the cable, the location of the maximum CM current can be found, which is the optimum position for the cable trap. Similarly, the effectiveness of a cable trap can be measured with a current clamp on either side of the trap. For repeatability, these measurements should be made with the cable held at a fixed distance over a ground plane.

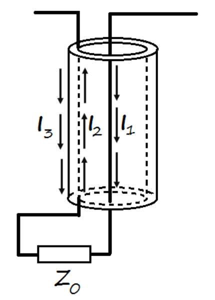

Figure 2: *Coaxial cable*

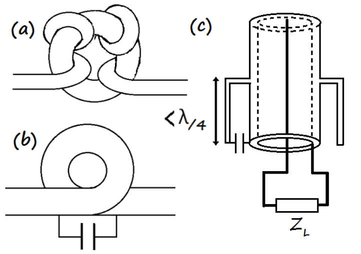

Figure 3: *Cable traps: (a) ferrite choke, (b) tank circuit and (c) bazooka.*

Figure 4: *Current clamps*

Summary: Common mode current present on the outside of a coaxial cable electromagnetically couples the cable, and the probe, to the surrounding environment. Cable traps can be used to block these common modes, by creating a high impedance for the CM signal. Three common trap designs were presented, and a method to measure their efficiency using current clamps was described.

References: [1] J. Mispelter *et al*, Imperial College Press 2006 [2] Kraus *et al*, McGraw-Hill Company, 1999 [3] D.M. Peterson, *CMR-B* 19B(1), 2003. ***Acknowledgements:*** Supported by CIBM of the UNIL, UNIGE, HUG, CHUV, EPFL and the Leenaards and Jeantet Foundations.