Coupled Transmission Lines as a Time-Domain Directional Coupler

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Abstract

Directional couplers are a well-established microwave subject, various bibliographies and texts being available. Here our attention is limited to TEM transmission-line couplers for their potential time-domain application. This is further restricted to *uniform* two-conductor plus reference transmission lines of finite length because, as we shall see, the coupler samples the waveform of interest over a time window of twice the transit time in the coupler without distorting the waveform. This can be compared to another type of directional coupler which senses the time derivative of the waveforms [C. E. Baum, "A Sensor for Voltage, Current and Waves in Coaxial Cables", Sensor and Simulation Note 447, 2000]. These kinds of directional couplers have application to various measurement situations, including measuring the returning transient signal in a radar antenna which is also used for transmission of the radar pulse. Our general derivation covers previous work with some extension. Note that some authors refer to this type of device as a contra-directional coupler.

Here we show that a traditional type of transmission-line directional coupler can be made to operate for temporal waveforms as well. There is a time-window of width $2t_\ell$ during which the coupled waveform is the same as the incident waveform times a constant. This requires that, in the simplest operation, $2t_\ell$ be longer than the time duration of the pulse of interest. One can extend this to longer times by appropriate data processing, noting the more complete description of the scattering-matrix elements. Our general approach to the theory has revealed various cases of potential interest. The fully symmetric case (symmetry between wires 1 and 2 as well as source and load impedances) with identical resistive impedances (cable characteristic impedances) on all four ports gives rather simple final answers. There are, however, more general cases that still lead to zero transmission form port 1 to port 4 (the directional-coupler criterion) in 4.

Noting that a transmission-line model is used for the coupler, there are some errors in modeling a real such device. In particular, at frequencies high enough that radian wavelengths are not large compared to the cross-section dimensions, a full wave analysis may be required. Near the ports the abrupt changes in the cross-section geometry may make evanescent modes significant there.