Integrated low-loss balun for Vivaldi antennas

E.W. Reid, L. Ortiz-Balbuena and K. Moez

A low-loss balun is presented that can be integrated on the low-permittivity substrates usually used in the construction of the adjoining Vivaldi antenna for improving the antenna radiation. However, it also increases the unwanted radiation of the feeding balun required for impedance matching and mode conversion. The radiation losses of the balun are reduced by limiting the size of balun, which is achieved by cladding the balun with slabs of high permittivity dielectric.

Introduction: Vivaldi antennas are extensively used for radar applications to form dense, two-dimensional arrays to operate over a large frequency range [1]. Such arrays can be designed to produce a narrow symmetrical beam, sensitive in two mutually orthogonal polarisations, with low sidelobe level. Vivaldi antennas have been built to operate over frequencies from less than 1 GHz to a few hundred GHz [2, 3], and have evolved to several different forms. However, most common are those printed on radio frequency circuit board material, which is the kind presented in this Letter. It has been reported in the literature that Vivaldi antennas can operate over a 5:1 frequency range [1]. To utilise as much of the antenna's inherent bandwidth as possible, the design of a balun with equal bandwidth is important as it facilitates the necessary impedance matching and mode conversion (balanced-line to unbalanced-line). Vivaldi antennas are travelling-wave antennas that are fed with opposite potentials with respect to a common ground, thus requiring a balanced-line feed. It is a well known fact that a direct connection with an unbalanced transmission line to a balanced line fed antenna can cause both the antenna and the adjoining transmission line to radiate (e.g. the outer sheath of coaxial cable radiates). This condition causes a poor transfer of energy to/from the antenna, and will adversely alter its radiation pattern.

Trifunovic and Jokanovic [4] introduced a numerical method for designing a fourth-order balun with equal ripple response. In recent publications there are a large number of broadband balun designs involving printed circuit board material [5, 6]. In this Letter we address the problem of constructing a fourth-order Marchand balun on a Vivaldi antenna unit. We used low-permittivity laminate to facilitate radiation from the antenna. To reduce dissipative losses and unwanted radiation from the balun, it was clad with a thin slab of high-permittivity dielectric material. To adjust line impedances to values required by the design, the exposed metal side is clad with a dielectric superstrate. This reduces the physical size of the balun components and decreases unwanted radiation.

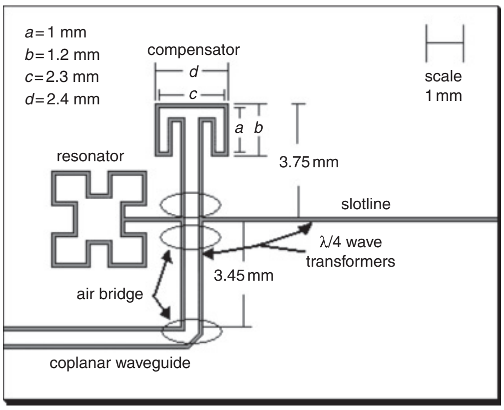

Fig. 1 *Proposed balun*

Proposed balun construction: The balun is constructed of two quarter wavelength transformers (QWTs), a resonator and a compensator. The design process starts from specification of the lower (f_L) and upper (f_U) passband frequencies over which the balun must operate. We have designed the balun to work in the frequency range 2–7.5 GHz, with a return loss at least 15 dB. Transmission line length, expressed in wavelengths, is given by $\lambda_g = v_p/f_0$ at the band centre frequency f_0, where v_p is the phase velocity on the line. Fig. 1 shows a diagram extracted from a photograph of the proposed balun. Fig. 2 shows an equivalent circuit model, where Z_b, Z_{ab}, Z_{01} and Z_{02} are the characteristic impedances of the quarter wavelength transmission line sections forming the compensator, resonator, input QWT (coplanar waveguide) and output QWT (slotline), respectively. An appropriate set of dimensions for all these components was found by trial-and-error through EM simulation. This was constructed using a substrate and superstrate thickness of 0.8 and 1 mm with dielectric constants of 2.3 and 6.0, respectively.

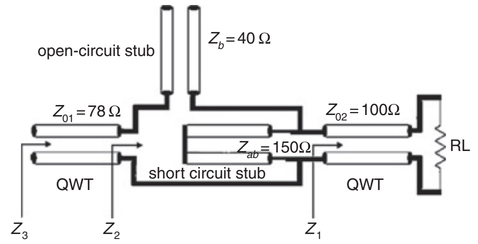

Fig. 2 *Equivalent circuit model for fourth-order Marchand balun*

The resonator is constructed using quarter wavelength slotline sections that are connected in series at the cross-junction in order to double the impedances to the values called for by the design. The compensator comprises two quarter-wavelength slotlines, and the lines are connected in parallel at the cross-junction. This decreases the impedance to a value called for by the design.

The largest dimension of the resonator and compensator is less than 1/12th of the free-space wavelength at the highest operating frequency. This makes our design superior to other baluns reported in the literature. Conventional baluns used for Vivaldi antennas are physically large, which radiate and impair the antenna's pattern.

Three air bridges (semi-circular copper straps jumping over the centre conductor) are required to force the coplanar waveguide to propagate only odd-order modes, particularly the lowest-order mode.

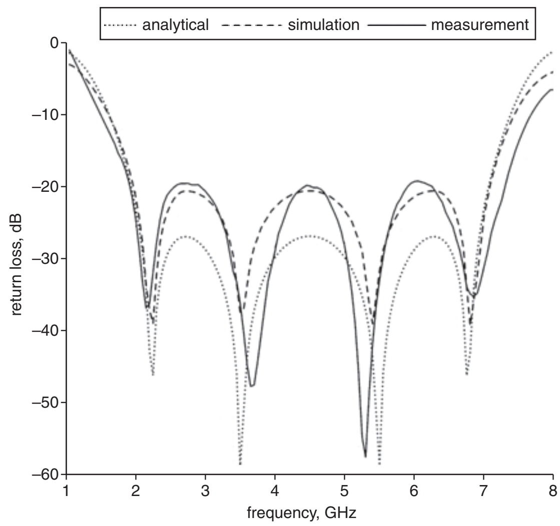

Fig. 3 *Comparison between analytically determined, simulated and measured return loss*

Results: Fig. 3 shows a comparison between the calculated, simulated and measured return loss of a balun. The analytically determined return loss curve has lobes with minimum return loss reaching 27 dB, whereas those found by simulation and measurement were 21 and 19 dB, respectively. The difference between these responses is attributed to the fact that the model does not account for interaction between components. Nevertheless, there is a very good agreement in the trend of all three curves. The frequency range over which the return loss is 19 dB or more is 2–7.5 GHz, or a ratio of 3.75:1. Low radiation leakage is important in preventing the appearance of unwanted sidelobes when the balun is used to feed an antenna. Through EM simulation, we found that the leakage owing to radiation increases with frequency from 0.01 to 0.1 dB for 2 and 7 GHz, respectively. There is a sharp increase in radiation leakage beyond 7 GHz, which is caused by net in-phase currents of the balun components and an increase in the balun's radiation resistance. The balun design addresses the unwanted balun radiation problem resulting in a reduction of radiation power loss of more than 50%.

Conclusions: This Letter presents a practical design for building a planar fourth-order Marchand balun using printed circuit board laminates with low permittivity. The measured return loss was greater than 19 dB over the frequency range 2–7.5 GHz. Our design can be scaled to other frequency ranges, which provides a general design for including a balun as part of a planar tapered slot antenna.

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