

## References

- 1 DARNELL, M., RILEY, N.G., and MELTON, D.: 'Tropospheric scatter propagation in the low-VHF band'. IEE 7th Int. Conf. on Antennas and Propagation, UK, University of York, UK, April 1991, CP-333, pp. 972-975
- 2 RAVARD, O.: 'Etude et modelisation de canaux de transmissions VHF intermittents'. PhD thesis, University of Rennes, France
- 3 COHEN, L.: 'Time-frequency analysis' (Prentice Hall PTR, New Jersey, USA, 1995)

## Full-wave analysis of choking characteristics of sleeve balun on coaxial cables

S.A. Saario, J.W. Lu and D.V. Thiel

An optimal design for a sleeve balun with maximum choking on a coaxial cable is determined using a full-wave body of revolution finite difference time domain method with perfectly matched layer boundary conditions. An analysis of the sensitivity of choke length  $L$  and outer diameter  $R_2$  on choking effectiveness was carried out. A balun with  $L = 77.5$  mm ( $0.232\lambda_0$ ) and  $R_2 = 8$  mm on a cable with  $R_1 = 2$  mm ( $R_2/R_1 = 4$ ) results in an  $S_{21}$  of  $-20$  dB at 900 MHz and  $-15.5$  dB at 2730 MHz. The isolation of the balun at 900 MHz is quickly degraded as the  $R_2/R_1$  ratio is reduced below 2. Increasing  $R_2/R_1$  to 8, results in a reduction of optimum balun length  $L$  to approximately  $0.215\lambda_0$ , approximately 14% shorter than the typical recommended length for an 'ideal' quarter-wave balun.

**Introduction:** Suppression of odd-mode cable currents on coaxial cables and metal wire structures is a fundamental concept in the operation of baluns. A sleeve balun is one type of balun often encountered as a key component in antennas as well as in measurement environments for suppression of unwanted cable currents. It has been shown [1] that the connection of cables to a mobile handset under test can significantly perturb the impedance and radiation pattern measurement results of a handset antenna. Mitigation of these perturbation effects is possible by various forms of RF chokes or baluns applied to the cable [2-5].

In the practical application of sleeve baluns, the physical dimensions are difficult to define as there is little information on the design of sleeve balun chokes. The American Radio Relay League (ARRL) briefly discuss the dimensions of an operational quarter-wave sleeve balun, recommending that the diameter of the sleeve should be 'fairly large' in comparison to the coaxial cable. For a 0.5-inch-diameter cable, a sleeve of 2 inches is recommended [6], giving a  $R_2/R_1$  ratio of 4.

In this Letter, the choking characteristics of a sleeve balun are investigated with respect to variation of physical dimensions. To the knowledge of the authors, a full-wave analysis of a sleeve balun with an optimal solution has not been published to date.

**Numerical modelling:** The body of revolution (BOR) finite difference time domain (FDTD) method is used to numerically model the rotationally symmetric structure of a choke on a coaxial cable as shown in Fig. 1. The simulation space used to model the structure in the BOR two-dimensional (2D) model was  $200\Delta r$  and  $400\Delta z$  where  $\Delta r = \Delta z = 0.5$  mm. The radius of the coaxial cable was  $R_1 = 2$  mm. The space increments that were used allowed fine resolution of fields within the balun and around the coaxial cable with approximately 660 cells per wavelength at 900 MHz.

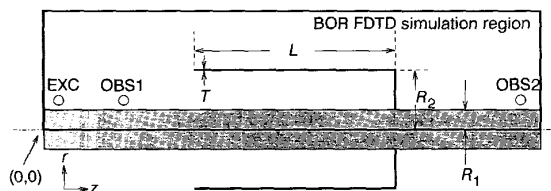


Fig. 1 Geometry for sleeve balun on coaxial cable for calculation of choking effectiveness

$R_1 = 2$  mm,  $T = 0.5$  mm,  $L = 65 \rightarrow 85$  mm and  $R_2 = 2.5 \rightarrow 15.5$  mm

The simulation was excited at the point  $(r, z) = (5, 10)$ , with a smooth compact pulse as shown at the EXC point in Fig. 1. The distance between the source point and the first observation point OBS1 at  $(r, z) = (5, 60)$  was sufficient to ensure that the incident wave had stabilised to a TEM mode and that evanescent modes had decayed. The transmitted pulse was recorded at OBS2 which was located at  $(r, z) = (5, 380)$ . The scattering parameters for the balun were calculated from the incident pulse at OBS1 and transmitted pulse at OBS2 using (1) and (2).

$S_{11}$  and  $S_{21}$  are calculated using the following expressions:

$$S_{11}(\omega) = 20 \log_{10}(F[I_{refl} - I_{inc}]/F[I_{inc}]) \quad (1)$$

$$S_{21}(\omega) = 20 \log_{10}(F[U_{trans}]/F[U_{inc}]) \quad (2)$$

where  $I_{inc}$  is the incident current pulse,  $I_{refl}$  is the reflected current pulse with the incident included observed at OBS1.  $I_{trans}$  is the transmitted current pulse observed at OBS2.  $F$  is the Fourier transform operator.

The width  $R_2$  and length  $L$  of the balun were stepped through from 2.5 to 15.5 mm and 65 to 85 mm, respectively, with the isolation  $S_{21}$  of the balun calculated at each point. These results are shown in Fig. 2. This was an exhaustive search of the simulation space around an expected 'good' result to gain an understanding of the isolation characteristics of the balun.

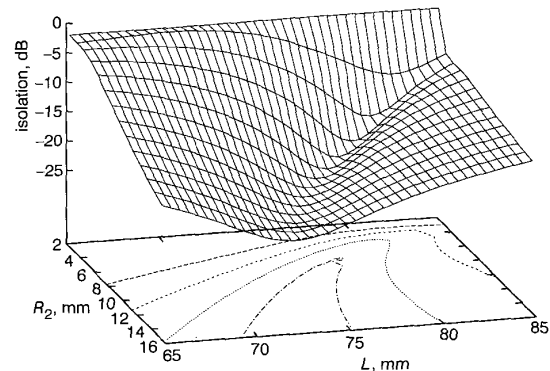


Fig. 2  $S_{21}$  for varying length  $L$  and width  $R_2$  of sleeve balun choke

Analysing the results for maximum isolation, from Fig. 2, the optimal length  $L$  for maximum isolation for a given  $R_2/R_1$  ratio is determined and is shown in Fig. 3. It can be seen that the optimal length of the balun  $L$  is approximately  $0.25\lambda_0$  for a very narrow balun, where  $R_2/R_1 < 2$ . However, as the  $R_2/R_1$  ratio is increased to 8, the optimal length decreases to  $0.215\lambda_0$ , approximately 14% shorter than a quarter-wavelength.

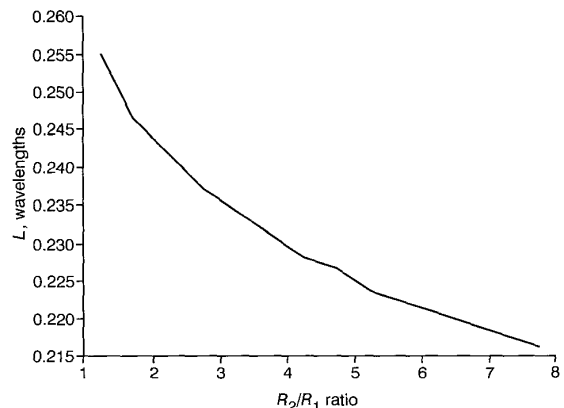


Fig. 3 Optimal length of sleeve balun  $L(\lambda)$  against  $R_2/R_1$  ratio of sleeve balun choke for minimum  $S_{21}$

The maximum isolation for an optimal length  $L$  balun at a given  $R_2/R_1$  ratio is shown in Fig. 4. It can be seen that for a very narrow balun where  $R_2/R_1 < 2$ , the isolation is less than  $-15$  dB and very sensitive to any variation in the diameter  $R_2$  of the balun. A balun

operating with these dimensions is impractical to make and operate owing to the excessive sensitivity of isolation.

As the  $R_2/R_1$  ratio is increased past 3, the isolation stabilises to approximately  $-20$  dB which is adequate for most applications. The variation in isolation becomes quite insensitive to variation in  $R_2/R_1$  which would be required for a robust physical implementation of a balun. The isolation sensitivity to variation in  $R_2/R_1$  and  $L$  is also clearly apparent in Fig. 2 with the optimal length region becoming wider at large  $R_2/R_1$  ratios.

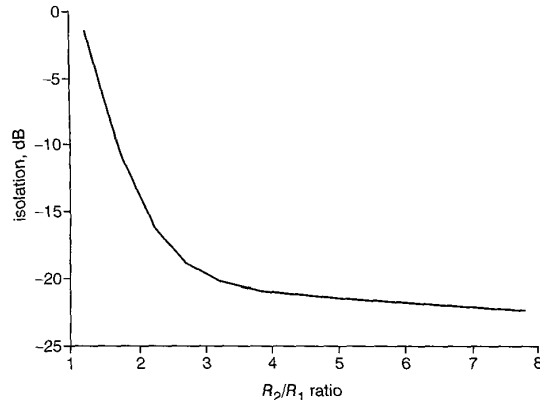


Fig. 4 Maximum isolation (dB) obtainable at optimal length  $L$  against  $R_2/R_1$  ratio of sleeve balun choke

The ARRL recommends a sleeve balun with a  $R_2/R_1$  ratio of 4 and  $L = 0.25\lambda_0$ : it was found that a balun with these dimensions gives an isolation of  $-10.9$  dB, which is significantly less than that achievable with an optimised length of  $L = 0.232\lambda_0$  giving an isolation of  $-20$  dB.

**Conclusion:** The choking characteristics of a sleeve balun were analysed using the 2D BOR FDTD algorithm. It was noted that as the  $R_2/R_1$  ratio of the balun was reduced below 2, the maximum achievable isolation of the balun was rapidly reduced and the isolation results were very sensitive to any variation in dimensions. For  $R_2/R_1$  values greater than 3, the balun was seen to be quite insensitive to variation in dimensions with an isolation of approximately  $-20$  dB up to an  $R_2/R_1$  ratio of 8. To achieve maximum isolation, the length of the balun had to be optimised. For  $R_2/R_1 = 1.5$ , the optimal length  $L$  for the balun was  $0.25\lambda_0$ , however, at  $R_2/R_1 = 8$ , the optimal length  $L$  was  $0.215\lambda_0$ , 14% shorter than a quarter-wave. It was found that the actual length of the balun is significantly less than a quarter-wavelength owing to the total electrical length of the balun ( $R_2 - R_1 + L$ ) and fringing fields around the open end of the balun. At  $R_2/R_1 = 4$ , as recommended by the ARRL [6], a balun which is insensitive to dimensional variation is obtainable, the isolation was calculated to be  $-10.9$  dB with  $L = 0.25\lambda_0$ , which is much less than  $-20$  dB which is achievable with an optimal length balun with  $L = 0.232\lambda_0$ . It was found that there is no significant advantage having a balun with  $R_2/R_1 > 3$ .

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#### References

- 1 SAARIO, S., THIEL, D.V., LU, J.W., and O'KEEFE, S.G.: 'An assessment of cable radiation effects on mobile communications antenna measurements', IEEE Symp. Antenna, and Propagation, Montreal, Canada, 1997, pp. 550–553
- 2 ICHELIN, C., OLLIKAINEN, J., and VAINIKAINEN, P.: 'Reducing the influence of feed cables on small antenna measurements', *Electron. Lett.*, 1999, **35**, (15), pp. 1212–1214
- 3 ICHELIN, C., POPOV, M., VAINIKAINEN, P., and HE, S.: 'Optimal reduction of the influence of RF feed cables in small antenna measurements', *Microw. Opt. Technol. Lett.*, 2000, **25**, (3), pp. 194–196

- 4 ARAI, H.: 'Measurement of mobile antenna systems' (Artech House, 2001), Chap. 2, pp. 38–40
- 5 BALANIS, C.A.: 'Antenna theory: analysis and design' (Wiley, 1998, 2nd edn.), Chap. 9, pp. 480–481
- 6 'The ARRL antenna book' (ARRL, 2000 19th edn.)

## 50 GHz frequency divider using resonant tunnelling chaos circuit

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An ultra-high-speed frequency divider using a resonant tunnelling chaos circuit is fabricated, which monolithically integrates a resonant tunnelling diode and a high electron mobility transistor. This frequency divider is based on the long-period behaviour of the nonlinear circuits generating chaos. The various frequency dividing operations are observed at the input frequency of 50 GHz. Chaotic operation is also observed.

**Introduction:** Resonant tunnelling devices have attracted much attention as practical devices because of their potential for highly functional, high-speed analogue and digital integrated circuits [1–5]. Recently, we proposed a novel frequency divider using a resonant tunnelling chaos circuit, which exploits a strong nonlinearity of the resonant tunnelling diode (RTD), and demonstrated the high-frequency operations up to 12 GHz [6–9]. This frequency divider has several advantages including variable frequency-dividing-ratio and low power consumption. In addition to these features, ultra-high-frequency operation is expected due to the simple circuit design. In this Letter, we demonstrate 50 GHz operations of the frequency divider MMIC composed of an RTD and a high electron mobility transistor (HEMT).

**Frequency divider:** Fig. 1 shows the configuration of the fabricated circuit. This frequency divider consists of a resonant tunnelling diode, an inductor  $L$  and a capacitor  $C$ . The basic operation of this circuit has previously been reported [6, 7]. This is a type of van der Pol oscillator having an input terminal. This circuit outputs various types of signal patterns including chaos, when an external oscillating signal with DC bias ( $V_{in} = V_0 + A \sin(2\pi ft)$ ) is applied.

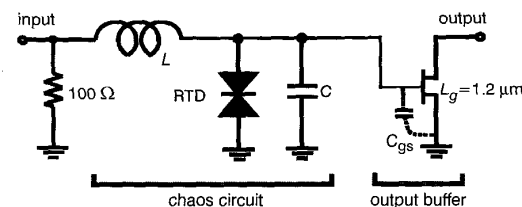


Fig. 1 Circuit configuration of fabricated frequency divider

The circuit was fabricated using InP-based RTD/HEMT integration technology [10]. The output buffer using a HEMT was integrated in the circuit. Without the buffer a high-frequency operation is impossible due to the interference with the measurement system. The circuit parameters are designed to be  $L = 0.8$  nH and  $C_{tot} = 0.08$  pF, so that the characteristic frequency  $f_{LC} (= 1/2\pi(LC_{tot})^{1/2})$  is  $\sim 19$  GHz. In general,  $C_{tot}$  is the sum of the capacitance  $C$  and the gate input capacitance of the HEMT  $C_{gs}$ . However, in the present study, no  $C$  was implemented, since the gate input capacitance was sufficiently large. The fabricated HEMT has the gate length of 1.2  $\mu\text{m}$ , gate width of 10  $\mu\text{m}$  and threshold voltage of  $-0.6$  V. The peak voltage, the peak current density and the peak-to-valley current ratio of the fabricated RTD are 0.25 V,  $4.5 \times 10^4$  A/cm<sup>2</sup> and 5 at room temperature, respectively.

**Experimental results:** The IC was tested using the on-wafer measurement system. A synthesised sweeper was used to supply a sinusoidal input signal via a microwave amplifier. DC voltages were supplied to the input and the output terminal through the bias network. Figs. 2a–d show measured input and output waveforms corresponding