4 MAAS, S.A.: 'Microwave mixers', 2nd edn. (Artech House, Boston, 1993), pp. 244–247

5 FUJIKI, Y., MANDAI, H., and MORIKAWA, T.: 'Chip type spiral broadside coupled directional couplers and baluns using low temperature co-fired ceramic'. Electronic Components and Technology Conference, 1999, pp. 105–110

6 LEW, D.W., PARK, J.S., AHN, D., KANG, N.K., YOO, C.S., and LIM, J.B.: 'A design of the ceramic chip balun using the multilayer configuration', *IEEE Trans. Microw. Theory Tech.*, 2001, **49**, (1), pp. 220–224

7 TANG, C.W., SHEEN, J.W., and CHANG, C.Y.: 'Chip type LTCC-MLC baluns using stepped impedance method', *IEEE Trans. Microw. Theory Tech.*, 2001, **49**, (12), pp. 1–8

8 WINTER, F., TAUB, J., and MARCELLI, M.: 'High-dielectric constant stripline band-pass filters'. Dig. IEEE MTT-S, 1991, pp. 555–556

9 KUMAR, B.P., BRANNER, G.R., and THOMAS, D.G.: 'A reduced size planar balun structure for wireless microwave and RF applications'. Dig. IEEE MTT-S, 1996, pp. 526–529

# Vertically periodic defected ground structure for planar transmission lines

J.-S. Lim, C.-S. Kim, Y.-T. Lee, D. Ahn and S. Nam

A vertically periodic defected ground structure (VPDGS) for microstrip. VPDGS has additional vertical periodicity of defects plus the conventional horizontal periodicity on the ground plane. The slow-wave factors and the predicted and measured performances are presented.

*Introduction:* There has recently been an increasing interest in microstrips combined with periodic structures such as photonic bandgap (PBG) [1] and defected ground structures (DGS) [2]. There have been applications of periodic structures to microwave circuits such as filters [2], power amplifiers [3, 4], and dividers [5]. One of the important properties of PBG and DGS is the increased slow-wave effect, which is caused by the equivalent inductance and capacitance. Hence, transmission lines with very high impedance can be realised and circuit size can be reduced using these properties [5].

The representative feature of the proposed vertically periodic defected ground structure (VPDGS) is that it is possible to organise the periodicity along not only horizontal but also vertical directions, while conventional periodic structures have the only horizontal array [2, 6] or spread structure all over the ground plane [1]. Owing to the vertically periodic structure, a much higher slow-wave factor can be obtained than existing periodic structures for the same physical length of transmission line.

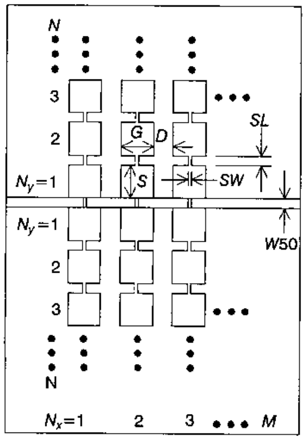

**Fig. 1** *Microstrip lines with VPDGSs on ground plane*
*a* Microstrip
Fr-4, $\varepsilon_r = 4.6$, $H = 0.75$, $W50 = 1.4$, $G = S = 5$, $D = 3$, $SW = 0.5$, $SL = 1.5$
All units are mm

*Structure of VPDGS:* Fig. 1 shows the structure of the microstrip lines combined with the proposed VPDGS. $N_x$ and $N_y$ mean the number of periodic defects along the horizontal and vertical direction, respectively. The VPDGS is the extended DGS along the vertical direction from the basic structure, which was presented in [2]. The unit DGS element can be expressed as $(N_x, N_y) = (1, 1)$ if the position and the number of DGS elements are expressed as a matrix form for convenience. All dimensions shown in Fig. 1, $N_x$, and $N_y$, are determined from the required frequency response.

*Slow-wave factors:* The slow-wave factors (SWFs) of the microstrip combined with the proposed VPDGS are expected to be greater than those of standard lines because of the additional equivalent L-C components. Fig. 2 shows the SWFs of the microstrip lines with the VPDGS and those of the standard lines with the same physical length up to the first resonance frequency. It is observed that the SWFs have increased greatly by VPDGS. Fig. 2 also shows that the VPDGS with larger $N_y$ for fixed $N_x$ (= 1) has lower cutoff frequency and higher SWF.

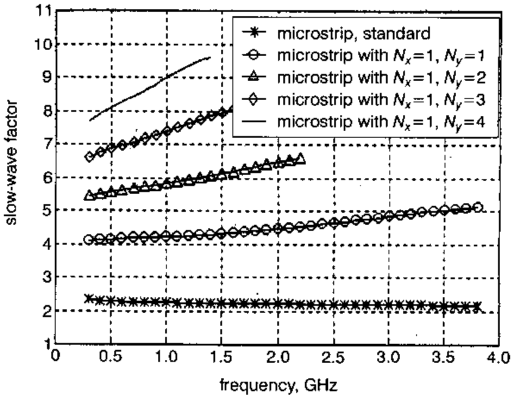

**Fig. 2** *Slow-wave factors of microstrip lines with VPDGS and standard lines*

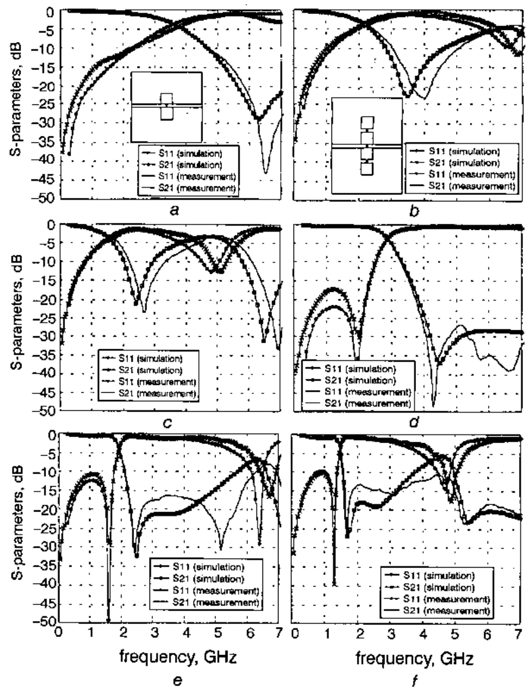

**Fig. 3** *Predicted and measured performance of microstrip lines with various matrices of VPDGS*
*a* (1, 1)
*b* (1, 2)
*c* (1, 3)
*d* (2, 1)
*e* (2, 2)
*f* (2, 3)

*Measured results:* Microstrip lines with various matrices of VPDGS were measured, and the results are shown with the predicted ones in Fig. 3. The EM simulations were performed on MicroWave Studio V3.0 and ENSEMBLE V5.1. The periodic passband and stopband, and steep cutoff characteristics are observed in the measured performances as predicted.

*Conclusion:* A vertically periodic defected ground structure for microstrips has been proposed using the basic dumb-bell-shaped DGS. The slow-wave factors of the microstrip lines with VPDGS are much larger than those of standard lines. It is expected that the proposed VPDGS will have many advantages when applied to microwave circuits.

*Acknowledgment:* This work was supported by the Brain Korea 21 Project.

*30 January 2002*
*Electronics Letters Online No: 20020483*
*DOI: 10.1049/el:20020483*

J.-S. Lim, Y.-T. Lee and S. Nam (*School of Electrical Engineering and Computer Science, Seoul National University, Seoul, Republic of Korea*)

E-mail: jslim@inmac3.snu.ac.kr

C.-S. Kim (*Telecommunication Basic Research Laboratory, Electronics and Telecommunications Research Institute, Daejeon, Republic of Korea*)

D. Ahn (*Division of Information Technology Engineering, SoonChunHyang University, Chungnam, Republic of Korea*)

## References

1 RADISIC, V., QIAN, Y., COCCIOLI, R., and ITOH, T.: 'Novel 2-D photonic bandgap structure for microstrip lines', *IEEE Microw. Guid. Wave Lett.*, 1998, **8**, pp. 69–72

2 AHN, D., PARK, J.S., KIM, C.S., KIM, J., QIAN, Y., and ITOH, T.: 'A design of the low-pass filter using the novel microstrip defected ground structure', *IEEE Trans. Microw. Theory Tech.*, 2001, **49**, pp. 86–93

3 RADISIC, V., QIAN, Y., and ITOH, T.: 'Broad power amplifier using dielectric photonic bandgap structure', *IEEE Microw. Guid. Wave Lett.*, 1998, **8**, pp. 13–14

4 LIM, J.S., KIM, H.S., PARK, J.S., AHN, D., and NAM, S.: 'A power amplifier with efficiency improved using defected ground structure', *IEEE Microw. Wirel. Compon. Lett.*, 2001, **11**, pp. 170–172

5 LIM, J.S., LEE, S.W., KIM, C.S., PARK, J.S., AHN, D., and NAM, S.: 'A 4:1 unequal Wilkinson power divider', *IEEE Microw. Wirel. Compon. Lett.*, 2001, **11**, pp. 124–126

6 YUN, T.Y., and CHANG, K.: 'Uniplanar one-dimensional photonic-bandgap structures and resonators', *IEEE Trans. Microw. Theory Tech.*, 2001, **49**, pp. 549–553

---

# Application of equal-weight orthogonal signalling to non-directed wireless infrared CDMA networks

P. Sedighian, M. Shahabadi and J.A. Salehi

An equal weight orthogonal (EWO) signalling scheme for wireless infrared code-division multiple access (CDMA) networks is studied. This scheme is primarily suggested to avoid the undesired need of threshold level estimation that is required in on-off keying (OOK)-CDMA systems. The bit error rate (BER) of an EWO-CDMA system, transmitting over non-directed links, is investigated. It is concluded that this signalling method presents an attractive choice due to both its simplicity and its BER performance compared with OOK-CDMA in a multipath infrared media.

*Introduction:* Infrared code-division multiple access (CDMA) schemes using sparse optical orthogonal codes (OOC) as their signature sequence are favoured for indoor wireless infrared networks [1, 2]. The modulation scheme commonly exploited in these networks is on-off keying (OOK). It is well known that the optimum demodulation of OOK-modulated optical signals requires a nonzero threshold level the value of which is a function of the optical power received from the desired cell, adjacent interfering cells, and background radiation. Thus, in wireless infrared links, the optimum OOK-demodulation can only be achieved if the threshold level is adjusted dynamically. To overcome the above shortcoming of OOK-CDMA, pulse position modulation (PPM)-CDMA and M-ary-CDMA have been suggested in the literature [1, 2]. It is the purpose of this Letter to propose an infrared wireless network that makes use of a different signalling scheme, i.e. equal weight orthogonal (EWO) signalling [3], for which the optimum threshold level is zero so that the need for its dynamical adjustment will be circumvented.

*EWO signalling:* In the ordinary OOK-modulator only '1' bits are assigned nonzero optical signals while in the EWO modulator both '0' and '1' bits are represented by nonzero signals chosen from a set of OOC [3] (Fig. 1*a*). This allows one to realise virtually bipolar signalling at the receiver side. To this end, the receiver estimates the transmitted bit by comparing the sampled outputs of two correlators connected to a photodetector (PD). Each correlator is matched to one of the OOCs assigned to '1' and '0' bits. We denote these codes as $C_1^{(i)}(t)$ and $C_0^{(i)}(t)$ where $i$ refers to the $i$th user. The schematic diagram of Fig. 2 depicts a realisation for an EWO-CDMA receiver in which the correlators are realised with switches. Considering the autocorrelation property of OOC [3], we chose $C_0^{(i)}(t) = C_1^{(i)}(t - nT_c)$ where $T_c$ denotes chip duration and $n$ is an integer. Under the assumption of chip-synchronous transmission of OOCs with autocorrelation and off-chip cross-correlation of unity, $n$ is chosen with regard to the following requirements: (i) the correlation of $C_1^{(i)}(t)$ and $C_0^{(i)}(t)$ must be zero to maximise the difference of the sampled correlators outputs; (ii) it is required that the interference by adjacent cells be maintained at the lowest possible level, thus $n$ should be chosen such that the distances of pulses in every sequence of '1' and '0' bits do not equal the distances of pulses in the spreading code of other users. For instance, in Fig. 1*b*, an interfering signal produced in cell 1 and received by the user in cell 0 is shown. Here, $n$ does not satisfy the above condition for cell 1, and the signal from that cell interferes with the desired signal of cell 0 in two chip positions.

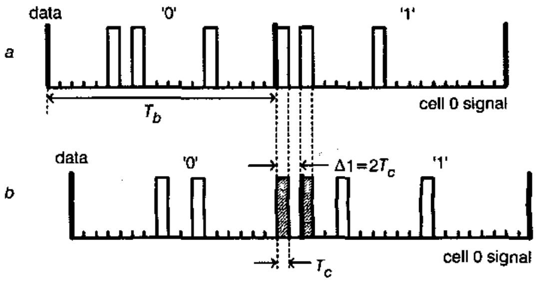

**Fig. 1** *Desired signal in cell 0, and signal in cell 0 received from cell 1*
*a* In cell 0
*b* In cell 0 from cell 1
$\Delta_1$: timing offset of cell 1

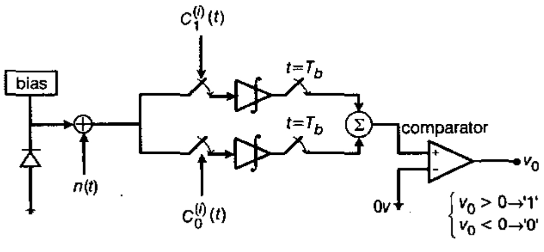

**Fig. 2** *Implementation for EWO-CDMA receiver*
$n(t)$: circuit thermal noise

*Bit error rate (BER) analysis:* For the BER analysis, a hexagonal cellular structure with a cluster size of three and a single user in each cell has been assumed. Considering only the down-link transmission, we determine the BER for the worst location of a user, which is at the vertex of a cell. By modelling the receiver of a photon counter [2], the