the boresight direction. The radiation patterns in the upper band are shown in Figure 5, and three different frequencies are measured across the passband. Again, broadside fields were obtained and the co-polarized fields were at least 18-dB stronger than the cross-polarized fields.

ACKNOWLEDGMENT

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REFERENCES

1. S.A. Long, M.W. McAllister, and L.C. Shen, The resonant cylindrical dielectric cavity antenna, IEEE Trans Antennas Propagat 31 (1983), 406–412.
2. K.M. Luk and K.W. Leung, (Eds.), Dielectric resonator antennas, Research Studies Press, U.K. 2003.
3. A.A. Kishk, X. Zhang, A.W. Glisson, and D. Kaifez, Numerical analysis of stacked dielectric resonator antennas excited by a coaxial probe for wideband applications, IEEE Trans Antennas Propagat 51 (2003), 1996–2006.
4. K.W. Leung, et al. Bandwidth enhancement of dielectric resonator antenna by loading a low-profile dielectric disk of very high permittivity, Electron Lett 33 (1997), 725–726.
5. Z. Fan and Y.M.M. Antar, Slot-coupled DR antenna for dual-frequency operation, IEEE Trans Antennas Propagat 45 (1997), 306–308.
6. T.A. Denidni and Q. Rao, Hybrid dielectric resonator antennas with radiating slot for dual-frequency operation, IEEE Antennas Wireless Propagat Lett 3 (2004), 321–323.
7. A. Buerkle, K. Sarabandi, and H. Mosallaei, Compact slot and dielectric resonator antenna with dual-resonance, broadband characteristics, IEEE Trans Antennas Propagat 53 (2005), 1020–1027.
8. K.P. Esselle and T.S. Bird, A hybrid-resonator antenna: Experimental results, IEEE Trans Antennas Propagat 53 (2005), 870–871.
9. A.K. Skrivervik, Z.F. Zurcher, O. Staub, and J.R. Mosig, PCS antenna design: the challenge of miniaturization, IEEE Antennas Propagat Mag 43 (2001), 12–27.
10. Product manual for Eccostock HiK powder, Emerson & Cuming microwave product, www.eccosorb.com/catalog/eccostock/HIKPOWDER.pdf.
11. G.P. Junker, A.A. Kishk, and A.W. Glisson, Input impedance of dielectric resonator antennas excited by a coaxial probe, IEEE Trans Antennas Propagat 42 (1994), 960–966.
12. G.P. Junker, A.A. Kishk, and A.W. Glisson, Multiport network description and radiation characteristics of coupled dielectric resonator antennas, IEEE Trans Antennas Propagat 46 (1998), 425–433.

MEASURED PATTERNS OF A RESISTIVE V-DIPOLE FED WITH A DOUBLE-Y BALUN

Jaikrishna Venkatesan[1] and Waymond R. Scott, Jr.[2]
[1] Spa
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109-8099
[2] Dept. of Electrical Engineering
Georgia Institute of Technology, Atlanta, GA

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ABSTRACT: *The performance of a double-Y balun feeding a resistive V-dipole is evaluated via antenna-pattern measurements. An optical link is constructed for containing the feedline radiation to a laser receiver unit and the antenna under test (AUT), hence avoiding the uncertainty caused by cable radiation in a conventional antenna pattern-measurement setup.* © 2005 Wiley Periodicals, Inc. Microwave Opt Technol Lett 48: 380–383, 2006; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.21356

Key words: *balun; double-Y; V-dipole; coplanar waveguide; coplanar strip*

1. INTRODUCTION

Symmetric antennas, such as the dipole and resistively loaded V-dipole, require a balanced antenna feed to radiate properly. If a symmetric antenna is fed directly with a coaxial line, the asymmetry between the conductors of the coaxial line and the arms of the antenna induces a common-mode current along the coaxial feed (the antenna feed becomes unbalanced). This common-mode current causes (i) unequal currents to flow along the arms of the antenna and (ii) the feedline to radiate. Hence, to properly transition from a coaxial line to a symmetric antenna, a balun is required.

Various versions of the double-Y balun have been investigated previously in the literature for use with balanced mixers [1–6]. The performance of the double-Y balun has been studied via VSWR and insertion-loss measurements; however, these measurements do not accurately characterize this balun when used for feeding an antenna. The double-Y balun of interest in this paper transitions from a coplanar waveguide (CPW) to a coplanar strip (CPS), and its performance when used for feeding a resistively loaded V-dipole is studied via antenna-pattern measurements. In section 2, the details of a double-Y balun designed to feed a resistive V-dipole are given. Section 3 describes the experimental setup constructed for measuring the far-field patterns of a resistive V-dipole, fed with and without the double-Y balun. The details of an optical link designed for use in the antenna pattern measurement setup, consisting of a laser modulator (LM) and laser receiver (LR) unit, are discussed in this section. The use of the optical link as part of the antenna pattern-measurement setup results in a novel approach towards characterizing the performance of the balun via accurate antenna pattern measurements. In section 4, the measured field patterns of a resistive V-dipole fed with and without the double-Y balun, are presented. The measured patterns are compared with the patterns computed numerically in [7].

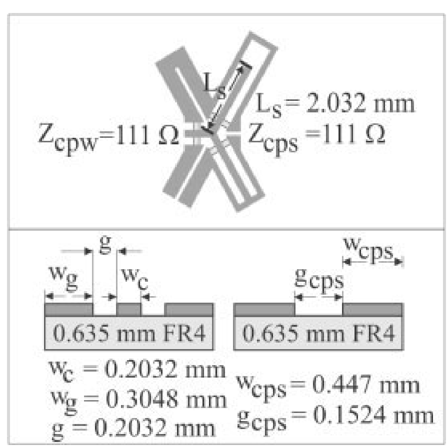

Figure 1 Illustration of double-Y balun designed to transition from a 111Ω CPW to a 111Ω CPS line

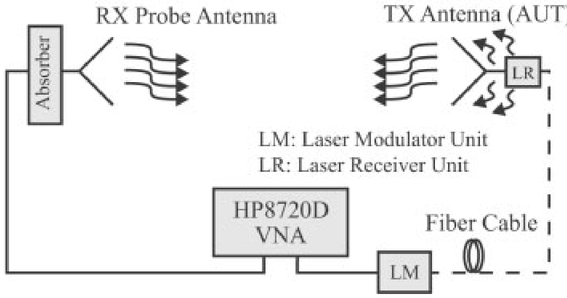

Figure 2 Experimental setup employing an optical link constructed for measuring antenna patterns. Optical link consists of a laser modulator (LM) unit, a laser receiver (LR) unit, and fiber cable linking both units

2. DOUBLE-Y BALUN DESIGN

A double-Y balun was designed for feeding the resistively loaded V-dipole described in [7]. The balun was designed to transition from a 50Ω coaxial line to a 200Ω resistive V-dipole [8]. Figure 1 illustrates the synthesized double-Y balun junction dimensions. Exponential impedance tapers were designed to transition from a 50Ω coaxial line to the 111Ω double-Y junction, and to transition from the 111Ω double-Y junction to the 200Ω resistive V-dipole. The length of the double-Y balun, including the impedance tapers, was 9.3 cm. CPW bridges were implemented using plated through-hole vias (with 6-mil via diameter) jumpered on the bottom of the 0.635 mm FR4 substrate ($\varepsilon_r \sim 4.4$).

3. EXPERIMENTAL SETUP: OPTICAL LINK

If the arms of a symmetric antenna are not fed with a perfectly balanced antenna feed, a common-mode current is induced along the antenna feedline, thus causing the feedline to radiate. The radiating feedline acts as an antenna, and its radiation characteristics vary with feedline properties (for example, length, position, and so forth). Hence, it becomes difficult to accurately measure the performance of an imperfect balun feeding a symmetric antenna via antenna pattern measurements. To conduct accurate pattern measurements, an experimental setup that contains the feedline radiation is required. Such an experimental setup is discussed as follows.

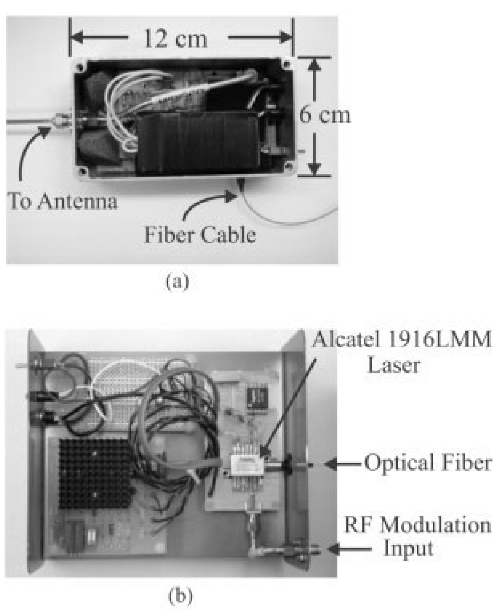

Figure 3 Illustration of the (a) laser receiver (LR) unit and (b) laser modulator (LM) unit. The dimensions of the LR unit are 12 × 6 × 4 cm

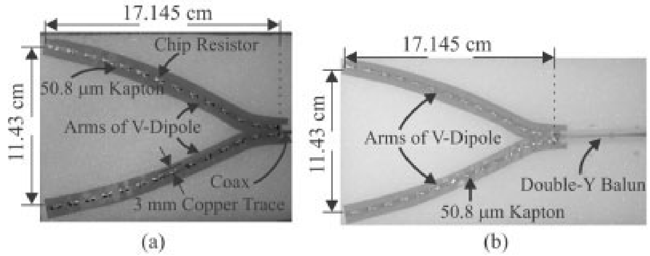

Figure 4 Illustration of resistively loaded V-dipole in [7] fed with (a) a coaxial line and (b) the double-Y balun

Figure 2 illustrates the experimental setup constructed in this work for measuring the antenna patterns of a resistive V-dipole fed with and without the double-Y balun. An optical link, consisting of a LM unit and a LR unit, was designed as part of the experimental setup. The optical link replaces a coaxial line that would otherwise carry the signal from the network analyzer to the antenna under test (AUT). The LM unit modulates light with the RF signal from the vector network analyzer, and transmits the modulated light via the fiber-optic cable to the LR unit. The LR unit recovers the RF signal and amplifies the signal for transmission by the AUT. The optical link allows the feedline radiation to be contained to the AUT and the LR unit (fiber cable is transparent to microwave signals). Figure 3(a) illustrates the LR unit, and Figure 3(b) illustrates the LM unit. An Alcatel 1915DMO laser receiver module was used in the LR unit, and an Alcatel 1916LMM laser modulator was used in the LM unit. The AUT and the LR unit were mounted on a rotary positioner, and the stationary receive probe (resistive V-dipole fed with a double-Y balun) was embedded in microwave absorber. The measurement system was automated using a PC running LabVIEW [8].

Figure 4(a) illustrates the resistively loaded V-dipole in [7] fed directly with a coaxial line (models an unbalanced feed). Figure 4(b) illustrates the resistive V-dipole fed with the double-Y balun. The V-dipole was printed on Kapton substrate, and the resistive profile was realized using chip resistors.

4. MEASURED PATTERNS

Normalized far-field E-plane patterns for the resistive V-dipole, fed with and without the double-Y balun are illustrated in Figures 5–9. The measured patterns for the resistive V-dipole

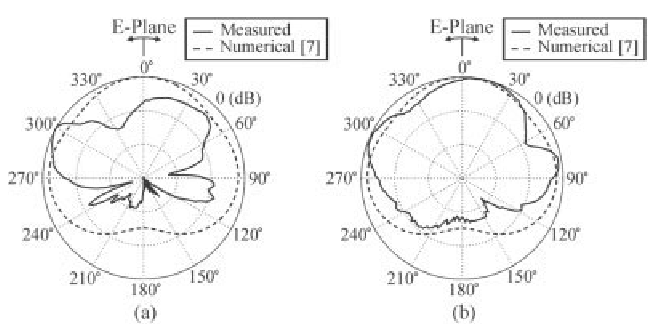

Figure 5 Normalized pattern of resistively loaded V-dipole at 1 GHz fed (a) without the double-Y balun and (b) with the double-Y balun. The numerical pattern assumes a balanced antenna feed and does not model the LR unit

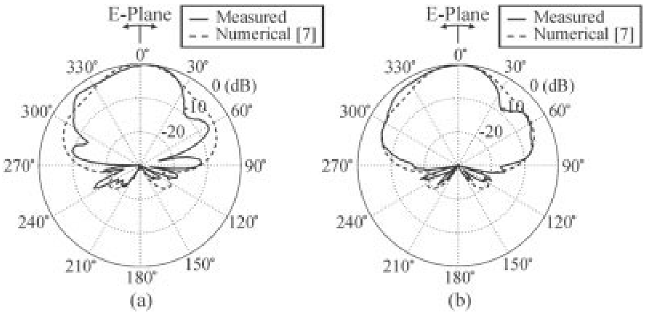

Figure 6 Normalized pattern of resistively loaded V-dipole at 2 GHz fed (a) without the double-Y balun and (b) with the double-Y balun. The numerical pattern assumes a balanced antenna feed and does not model the LR unit

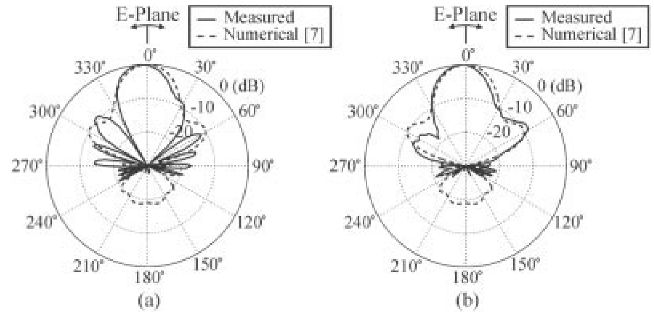

Figure 8 Normalized pattern of resistively loaded V-dipole at 4 GHz fed (a) without the double-Y balun and (b) with the double-Y balun. The numerical pattern assumes a balanced antenna feed and does not model the LR unit

are compared with numerical patterns computed using the method of moments (MoM) as in [7]. The numerical model corresponds to a balanced feed and does not include the LR unit used in the measurements. The patterns of the resistive V-dipole at 1-GHz fed with and without the double-Y balun are illustrated in Figure 5. The pattern for the V-dipole fed without a balun is distorted near broadside and additional nulls and sidelobes appear in the back region. These additional nulls and sidelobes also occur at 2 GHz, as illustrated in Figure 6. Figure 7 compares the patterns for the resistive V-dipole at 3 GHz, fed with and without the double-Y balun. The pattern for the V-dipole fed without the balun exhibits a null near 60°. Additional sidelobes are also present in the pattern of the V-dipole fed without the balun. In contrast, the pattern for the V-dipole fed with the double-Y balun does not exhibit any nulls. The nulls and additional sidelobes become more pronounced at 4 and 5 GHz for the V-dipole fed without the double-Y balun, as illustrated in Figures 8(a) and 9(a), respectively. The patterns at 4 and 5 GHz for the V-dipole fed with the double-Y balun are illustrated in Figures 8(b) and 9(b), respectively. These patterns agree well with the numerical patterns for a balanced resistive V-dipole. Some discrepancy can be expected between the measured and numerical patterns due to manufacturing tolerances as well as the exclusion of the LR unit from the numerical model. The measured relative gain between the resistive V-dipoles fed with and without the double-Y balun, at 0°, is illustrated in Figure 10. The relative gain plot illustrates increased gain for the V-dipole fed with the double-Y balun relative to the V-dipole fed without a balun. The lower gain for the V-dipole fed without a balun can be attributed to: (i) impedance mismatch between the coaxial feedline and resistive V-dipole and (ii) nulls in the pattern due to unbalanced antenna feed.

5. CONCLUSION

The feasibility of using the double-Y balun for feeding a resistive dipole has been investigated in this work via antenna pattern measurements. To accurately measure antenna patterns of a resistively loaded V-dipole fed with and without the double-Y balun, an experimental setup, employing the use of an optical link, was constructed. The optical link serves to contain the feedline radiation caused by an imperfect balun feeding a symmetric antenna, hence enabling accurate antenna pattern measurements to be conducted. Measured far-field patterns for the V-dipole fed without a balun exhibited additional nulls and sidelobes. In contrast, the measured far-field patterns for the V-dipole fed with the double-Y balun did not exhibit the additional nulls and sidelobes, and approximated the numerical patterns computed in [7] for a resistive V-dipole with a balanced feed.

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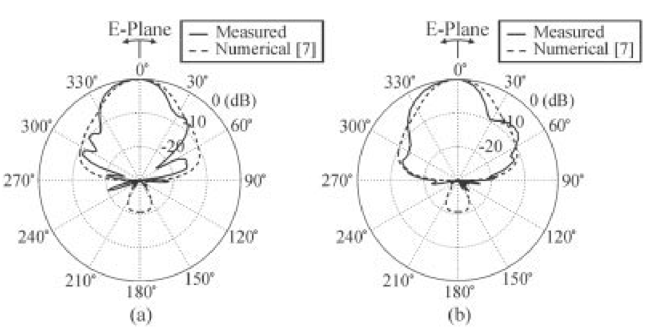

Figure 7 Normalized pattern of resistively loaded V-dipole at 3 GHz fed (a) without the double-Y balun and (b) with the double-Y balun. The numerical pattern assumes a balanced antenna feed and does not model the LR unit

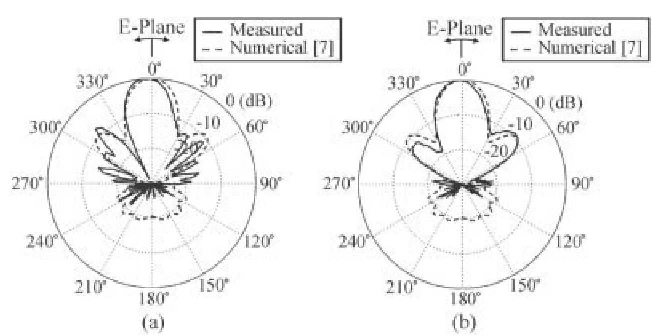

Figure 9 Normalized pattern of resistively loaded V-dipole at 5 GHz fed (a) without the double-Y balun and (b) with the double-Y balun. The numerical pattern assumes a balanced antenna feed and does not model the LR unit

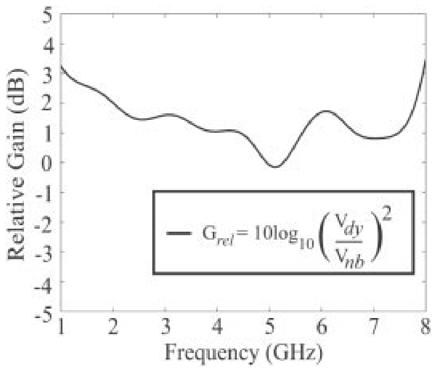

Figure 10 Plot of relative gain G_{rel} at 0° between resistive V-dipoles fed with and without the double-Y balun. V_{dy} is the voltage received by the RX V-dipole with the TX V-dipole fed with the double-Y balun. V_{nb} is the voltage received by the RX V-dipole with the TX V-dipole fed without a balun

REFERENCES

1. V. Trifunovic and B. Jokanovic, Four decade bandwidth uniplanar balun, Electron Lett 28 (1992), 534–535.
2. V. Trifunovic and B. Jokanovic, Review of printed Marchand and double-Y baluns: characteristics and application, IEEE Trans MTT 42 (1994), 1454–1462.
3. V. Trifunovic and B. Jokanovic, New uniplanar balun, Electron Lett 27 (1991), 813–815.
4. V. Trifunovic and B. Jokanovic, Double-Y baluns for MMICs and wireless applications, Microwave J 41 (1998), 70–92.
5. V. Trifunovic, A. Marincic, B. Jokanovic, Analysis of the parasitic effects in double-Y baluns, IEE Proc Microwave Antennas Propagat 148 (2001), 239–245.
6. B. Jovanovic, V. Trifunovic, and B. Reljic, Balance measurements in double-Y baluns, IEE Proc Microwave Antennas Propagat 149 (2002), 257–260.
7. K. Kim and W.R. Scott, Jr., A resistive linear antenna for ground-penetrating radars, SPIE Conf, 2004.
8. J. Venkatesan, Investigation of the double-Y balun for feeding pulsed antennas, Ph.D. dissertation, Georgia Institute of Technology, 2004.

PATH-LOSS CHARACTERISTICS IN SUBWAY TUNNELS AT 2.65 GHz

Myung-Sun Choi,[1] Do-Youn Kim,[2] Han-Shin Jo,[2] Jong-Gwan Yook,[2] and Han-Kyu Park[2]
[1] Korea Association of Information & Telecommunication (KAIT)
Seoul 137-070, Korea
[2] Dept. of Electrical and Electronic Engineering
Yonsei University
Seoul 120-749, Korea

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ABSTRACT: *This paper presents the measurement of electromagnetic wave propagation in subway tunnels at $f = 2.6425$ GHz. The main goal of this work is to obtain more accurate knowledge of the propagation characteristics in straight and curved tunnels. Measurements have been conducted in four different types of tunnel courses: a straight tunnel, two curved tunnels (with 245-m and 500-m radius of curvature, respectively), and a tunnel that has both straight and curved sections. From the measured results, we analyze and compare the differences between the straight and curved tunnels, particularly with regard to path loss and the effect of path loss arising from different curvatures, and the characteristics of the combined tunnel (the straight and curved tunnel). The findings presented here should prove helpful in the estimation of link budget for satellite DMB service in tunnels and the determination of accurate propagation characteristics in tunnels.* Microwave Opt Technol Lett 48: 383–386, 2006; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.21357

Key words: *propagation characteristics; straight and curved tunnel; combined tunnels; path-loss; satellite DMB service*

1. INTRODUCTION

Recently, satellite digital multimedia broadcasting (DMB) service has received much attention. In Korea, TU Media began to offer this service, which supports a variety of content and consists of 14 video and 24 radio channels, as of May 2005. According to statistics, the satellite DMB service will yield strong profits through the establishment of infrastructure and by offering services and content.

This service, however, has major unresolved issues related to signal propagation in the 2.6425-GHz band. In particular, the signal propagation fades due to shadowing and blocking of the direct satellite path. For the next 10 years, these shadowing and blocking areas will increase rapidly while listeners/viewers of this service will spend more time in these areas. Thus, the environments for DMB are expected to be further extended into these areas, which will include underground shopping malls, subways, and so forth. For implementing this service, radio propagation characteristics need to be clarified, since the path-loss and fading characteristics affect the coverage and quality of service [1, 2].

Much work has already been done to characterize wave propagation in underground areas. Studies have measured and simulated the electromagnetic wave propagation in other bands and simulations alone have been conducted in the same band [3–7]. However, there has been insufficient investigation involving measurements in the underground areas at the DMB band. Thus, this paper deals with the measurement of electromagnetic wave propagation in subway tunnels, which are major underground areas, at $f = 2.6425$ GHz. The main goal of this work is to obtain more accurate knowledge of the propagation characteristics in straight and curved tunnels.

2. MEASUREMENT SETUP

2.1. Measurement Equipment

The measurement setup, shown in Figure 1, consists of three parts as follows. The transmit part is composed of a Harada YG26G091392-1 model Yagi antenna and an Anritsu MG3691A CW generator. Here, the Yagi antenna has a 9-dBi directional gain and is fixed at a height of 2 m above the ground. The CW generator, whose maximum transmit power is 20 dBm, operates at a single tone at 2.6425 GHz. In the receive part, the transmitted signals are picked up by the receiver, an Anritsu S332D spectrum analyzer with a receive antenna. The receive antenna is omnidirectional and is located 1.8 m above the ground. Also, the receiver can instantaneously measure signals between 0 and −90 dBm. Here, considering 20-dBm transmitter power and 9-dBi transmit antenna gain, the maximum system path loss is 119 dB. In the record part, a notebook computer is used as a data collector for subsequent analysis. The received power levels were recorded by the spectrum analyzer every two seconds, and thus the received signal was gathered at a distance of 1.2 m.