Design and Development of Printed Antenna Remote Units for Optically Distributed Mobile Communications

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***Abstract*—The first demonstration of a printed antenna remote unit (ARU) for optically distributed mobile communications compliant with the 1.9-GHz PCN specifications is presented. The ARU consists of a cavity-backed printed antenna with appropriate RF and photonic circuitry. The ARU is low cost, compact, robust, and can be easily positioned in typical microcell/picocell sites. A summary of the design procedure for the ARU and the measured results are given. The developed ARU is a key component for the successful deployment of future optically distributed microcellular mobile communications systems.**

***Index Terms*—Hybrid integration, printed antennas, RF photonic link.**

I. Introduction

FIBER-OPTIC microcellular systems have attracted much attention recently and are proposed to satisfy the increasing demand on mobile and personal communications. The important advantages of microcell architecture over more conventional mobile systems include: low transmission power due to the smaller cell size; reduction in the cost of deployment as all the processing and signaling procedures takes place at the central base station and therefore minimal equipment is required at the antenna remote unit (ARU); and increased system capacity as the frequency resources can be more effectively used [1], [2]. Optically distributed transmission is preferred between the central base station and the microcell base stations to take advantage of the salient features of optical fiber technology, such as low attenuation.

In this letter, we present the first printed ARU suitable for the frequencies allocated for the personal access communications system (PACS) [3]. The up- and down-link frequencies are 1850–1910 and 1930–1990 MHz, respectively. A hybrid integration approach for the ARU is adopted. Here, the microwave and optical components are mounted on a common substrate that is connected to the antenna. Printed antenna technology is utilized for this application due to its low cost, light weight, and ease of integration with the radio frequency (RF) and photonic components. A cavity-backed probe-fed stacked microstrip patch is used for the proposed ARU. An examination of all the components within the ARU will be given, including its overall performance.

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II. Antenna Remote Unit Configuration

Fig. 1 shows a schematic of the ARU that provides the interface between the antenna and the fiber-optic backbone of the network. In the downlink direction, the RF signal is directly modulated onto an optical carrier at the central base station and transported over the optical fiber to the ARU. At the ARU, a photodiode is used to recover the RF signal before amplification and then wireless distribution via the antenna. In the uplink direction, the received wireless signal is filtered before being amplified by a low-noise amplifier. The amplified signal then directly modulates the laser diode. The design of the photonic/microwave module and antenna module is discussed below.

A. Photonic/Microwave Module

A DFB laser diode was used for the uplink of the ARU as it offers high linearity and low relative intensity noise (RIN) to minimize intermodulation distortion and maximize the dynamic range of the system. A *Mitsubishi* DFB laser diode (FU-45SDF-37) was used here with a minimum bandwidth of 2 GHz, a RIN of −155 dB/Hz, and an efficiency of 0.17 mW/mA. A resistive matching was used to improve the impedance behavior of the laser diode. For the downlink of the ARU, an *MRV* p-i-n photodiode (MRPDFCAP075RPFC) was used with a bandwidth of 2 GHz and a responsivity of 0.85 A/W. The bias circuits for both photonic devices incorporated high-impedance quarter-wave microstrip lines. To reduce the impedance mismatch between the photodiode and the 20-dB amplifier (refer to Fig. 1), a single stub matching network was used.

To implement full-duplex operation of the ARU, a circulator and a bandpass filter were incorporated to provide isolation between the up- and down-link RF signals. Here, the *Nova Microwave 0192CAD* circulator with an isolation of 25 dB over the appropriate band was used. The bandpass filter was realized using parallel coupled microstrip lines on a Taconic substrate with a dielectric constant of 2.53 and a thickness of 0.508 mm. An optimized fifth-order Chebychev bandpass filter was implemented to provide sufficient isolation between the bands. The design of this filter was based on the technique outlined in

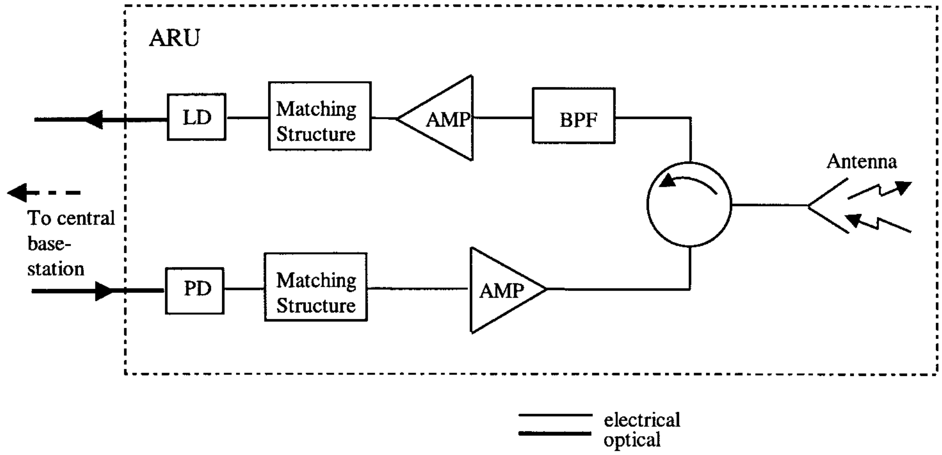
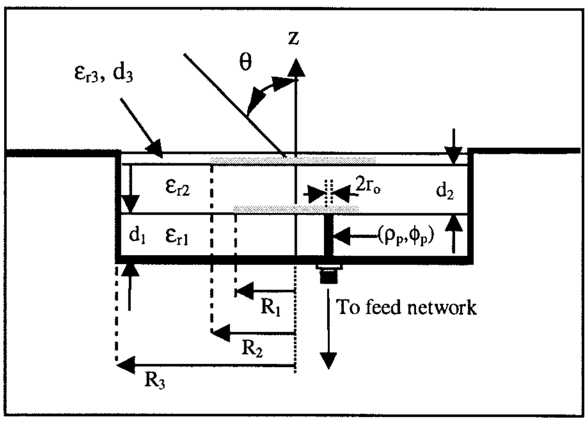
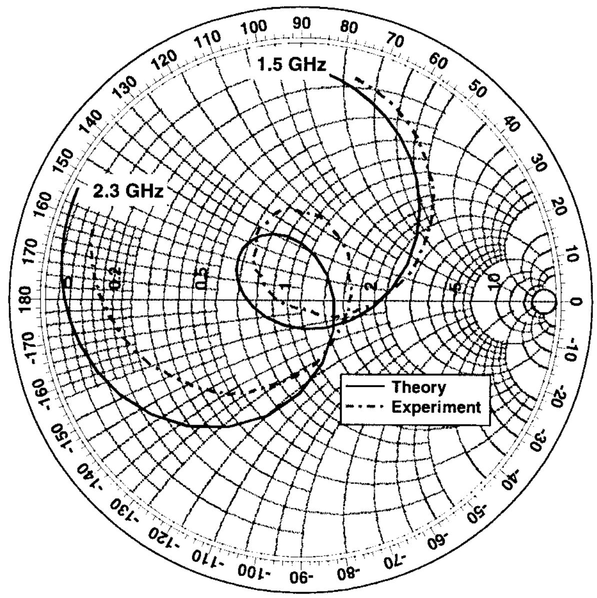


Fig. 1. Schematic of an optically distributed ARU.



(a)



(b)

Fig. 2. Schematic of the cavity-backed stacked patch antenna and input impedance (parameters: $\epsilon_{r1} = 2.2$, $d_1 = 3.048$ mm, $R_1 = 31.3$ mm, $x_p = 28$ mm, $y_p = 0$, $r_0 = 0.325$ mm, $\epsilon_{r2} = 1.07$, $d_2 = 10.0$ mm, $\epsilon_{r3} = 2.2$, $d_3 = 0.254$ mm, $R_2 = 34$ mm, $R_3 = 50$ mm).

[4] and therefore, for the sake of brevity, will not be repeated here. Using this filter in conjunction with the circulator resulted in a measured isolation between the up- and down-links of 45–50 dB. In the uplink direction, after filtering, a mini-circuits ERA-3SM amplifier with a gain of 20 dB, a noise figure of 3.6 dB and an IP_{3o} of 23 dBm amplified the wireless signal.

B. Antenna Module

For the ARU presented here, a probe-fed stacked cavity-backed patch was utilized. A probe-fed solution was chosen due to its good isolation between the radiating element and the feed network and its robustness. Robustness is an important factor considering the typical locations of the ARU's. The insert of Fig. 2 shows a schematic of the cavity-backed stacked patch antenna structure. To analyze this configuration, the antenna was designed using a full-wave spectral domain integral equation solution based on a Green's function technique [5]. As was reported in [6] a combination of foam and telfon fiberglass ($\epsilon_r \approx 2.5$) can provide reasonable impedance bandwidths for a stacked patch antenna. This finding also holds for a cavity-backed configuration. The predicted and measured input impedance behavior of the cavity backed stacked patch antenna is shown in Fig. 2 (refer to the figure caption for the relevant dimensions). As can be seen from these results, very good agreement between theory and experiment was achieved. The 10-dB return loss bandwidth is 23%, the largest ever reported for a cavity-backed probe-fed stacked microstrip patch antenna. The measured gain of the antenna was 7.35 dBi. The antenna is connected to the RF/photonic circuitry by means of a small coaxial cable adjoining the two ground-planes (see Fig. 3). The bias supplies for the RF and photonic components are housed between the antenna and the feed circuitry ground planes.

III. Overall System Results

The measurement of RF link loss was performed for the uplink between the ARU and a matched photodiode located at the central base-station over 1 km away via an optical fiber.

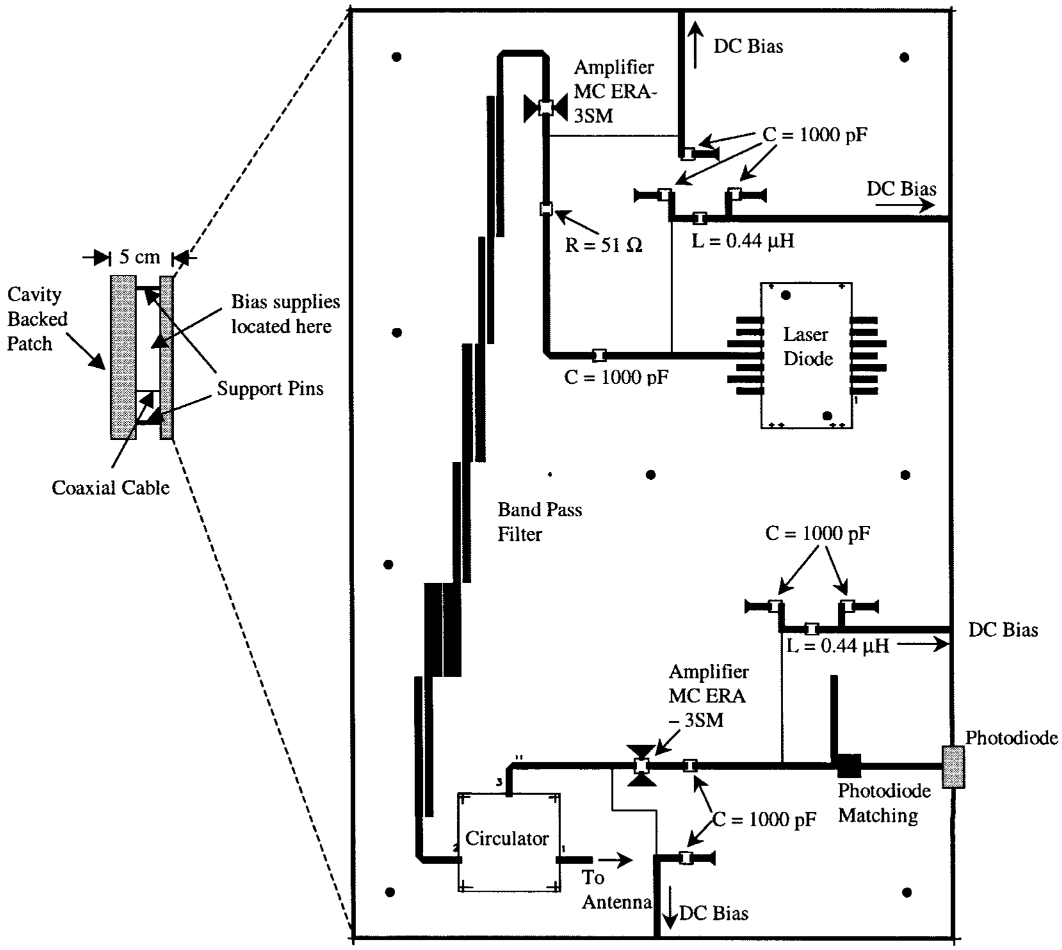


Fig. 3. Microwave/photonic module circuit layout.

A minimum transmission loss of 5.8 dB at a frequency of 1.9 GHz was measured. The carrier-to-noise ratio (CNR) was measured and calculated at the center frequency of uplink band as a function of optical modulation index (OMI). For an OMI of 25%, the CNR was approximately 75 dB. The spurious free dynamic range (SFDR) of the uplink was measured as 105 dB.Hz$^{2/3}$. This value satisfies the requirements for an ARU in a PACS as reported in [2]. Assuming a handset transmit power of 10 dBm, a handset antenna gain of 0 dBi, and a path loss of 85 dB [1], the system will function within the required specifications [2] for distances up to 500 m. The calculated link noise figure was 12 dB. Fig. 3 shows the printed circuit layout of the ARU microwave and photonic components. The volume of the entire ARU is 20 $\times$ 20 $\times$ 5 cm, making it suitable for site locations such as telephone poles and sides of buildings.

IV. Conclusions

A printed antenna remote unit for 1.9-GHz PACS has been demonstrated. A hybrid integration approach incorporating microstrip technology was adopted where the RF and photonic components are mounted on a common substrate and connected to the antenna. The ARU meets the electrical and structural requirements for a microcellular system operating at 1.9 GHz. The ARU is a significant factor in the development of an optically distributed mobile communications system.

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