stages: the erlang-j, k is the combination of two erlangs with different shapes and the same scale parameter, while the erlang-j-k is the combination of two erlangs with different shape and scale parameters. This family of distributions is highly appreciated by researchers for achieving analytical results. Although both distributions fit with negligible levels of significance, the statistical distance is around half that of the exponential; according to Table 1 the erlang-j, k fits better than the erlang-j-k.

The second family consists of mixes of lognormals. The generalisation, not yet proven, of the logarithmic human perception of time in the range of the telephone call duration seems to be supported by good significance levels in field studies [7]. The best fit is attained by the lognormal-3 (a mixture of three lognormals) with a significance close to 10% (Fig. 1). The spikes in the empirical pdf contribute to hinder the adjustment and lower the significance level. It is possible to remove these spikes by estimating the percentage of occupancies due to immediate hand-off, as is done in [6]; in this work we prefer to keep them, because good significance levels can be reached without altering the sample. When simulations are carried out, the single lognormal distribution represents a good trade-off between simplicity and accuracy.

Results closer to the system reality will obviously be achieved by using the lognormal-3 distribution. The lognormal-2, not included in Table 1, only slightly improves the significance of the lognormal.

The same investigation was performed for different times of day, and the significance ranking for the different candidate distributions remains the same. When data belonging to different cells and/or frequencies are taken, the ranking also holds: the average, coefficient of variation and statistical significance change along with the load, shape, size and mobility in the new cell, but the order in which the distributions fit the empirical data is kept. This gives this work a more general scope, as the conclusion that lognormal distributions fit better than the memoryless type is sustained on statistical analysis for samples belonging to many different situations.

Other statistical results: During the night charging period, the average holding time grows from 40.6 to 63.3s. As possible causes for this higher average, we can mention the lower mobility and the longer whole call duration due to a lower charging rate. The squared coefficient of variation also grows from 1.7 to 2.9. The explanation for this higher value is not so obvious, but the more personal (less professional) character of the whole conversation tends to make the data collection more sparse in time.

In our study, 76% of the occupancies have at least one hand-off; 45% have one, while 31% have both in and out hand-offs. All these occupancies are distorted by the cellular phenomenon: they are a fraction of the whole call. This mobility should be considered as high. Since during the busy hour the mean whole call duration is 113 s, each mobile station visits on average 113/40.6 = 2.78 cells.

Summary: Although by using analytical tools it can be concluded that the channel occupancy in cellular telephony follows an exponential distribution, field studies reveal that this distribution shows a poor fit with the empirical data. A mixture of lognormal distributions, which fits the whole call duration in conventional telephony very well, also gives the best result when the random variable is the dwell time in mobile telephony. There are other simpler pdfs which fit better than the exponential one: single lognormal and erlang-j,k. The latter can be represented as a combination of memoryless stages, which is an advantage when the analytical research is performed. Other statistical figures concerning different charging periods and the mobility rate have also been supplied.

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Division-free duplex for wireless applications

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Division-free duplex is proposed for future wireless systems, thus providing simultaneous duplex radio transmission on a division-free basis. The required duplex isolation can be achieved by electronic interference cancellation operating at both RF and baseband, with results from an experimental RF system yielding some 72dB duplex isolation at 1.8GHz for 200kHz channelisation.

Introduction: The use of frequency division duplex (FDD) is dominant in current cellular mobile systems, whereas time division duplex (TDD) is widely used in cordless applications. While present wireless systems are facing the ever-growing demand for services, novel duplex schemes offering significantly increased spectral efficiency are obviously attractive. With the rapid development of electronic technology in radio frequency (RF) circuit design and digital signal processing (DSP), it becomes increasingly possible to use an electronic process for duplex isolation, thus permitting simultaneous two-way information transfer over a common radio channel with all the benefits of enhanced spectral efficiency.

This Letter presents a novel duplex scheme known as *division-free duplex* (DFD), and the architecture of a DFD mobile radio transceiver. Further, the results from an experimental test-bed operating at 1.8GHz are also presented.

DFD radio architecture: The required duplex isolation for handheld terminals for second-generation systems is between 120–160dB [1], with cellular systems demanding higher isolation due to the large cell network deployment. Future wireless systems will inevitably use small cells, mainly because of the expected huge number of subscribers and the significantly improved services [2]. Also, proposals for air interface standards in future systems suggest a transmitted power level between +11 and +13dBm [3], ~10dB lower than that in second-generation systems, thus reducing the duplex isolation requirement. Here, it is shown that an electronic means has been developed that is currently capable of providing 72dB of duplex isolation using RF signal processing. This level, combined with a baseband echo canceller, would be sufficient for DFD operation in both cordless systems and urban cellular networks.

Self-induced co-channel interference is the main problem facing the DFD scheme. Without sufficient transmit-receive isolation, the strong locally transmitted signal will firstly feed-back to the receiver input directly via the antenna and other coupling paths inside the transceiver, and thus dominants in the duplex isolation requirements. In addition, radiowave reflections in the vicinity of the transceiver also cause further interference. This interference depends greatly on the environment, but is weaker because of the considerable path loss experienced. Hence, the suppression of the direct interference is the most important aspect of this design. We propose here to employ a number of electronic means in order to obtain the necessary isolation required for DFD operation [4]. Fig. 1 gives the architecture of DFD radio transceiver, which includes a dual-antenna, an adaptive RF echo canceller and an adaptive baseband digital filter. By employing two individual antennas for transmission and reception, some 27dB of isolation can most easily be achieved, even for the hand-held applications, which is higher than that achievable from a conventional circulator.

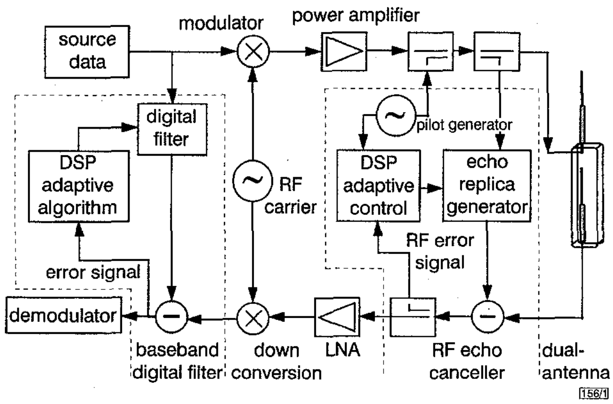

Fig. 1 *Architecture of DFD mobile radio transceiver*

Further suppression of the direct feedback interference is needed prior to the low noise amplifier (LNA) in order to avoid nonlinear operation. An RF echo canceller is therefore used prior to the LNA, which currently provides up to 45dB of isolation enhancement using a pilot-based control scheme, thus providing the optimum cancellation regardless of changes in environment. Further cancellation can also be obtained using wireline echo cancellers [5], which can provide up to 60dB echo suppression at a sample rate of 2.6MHz [6], thus illustrating that an overall transmit-receive isolation of some 130dB is possible.

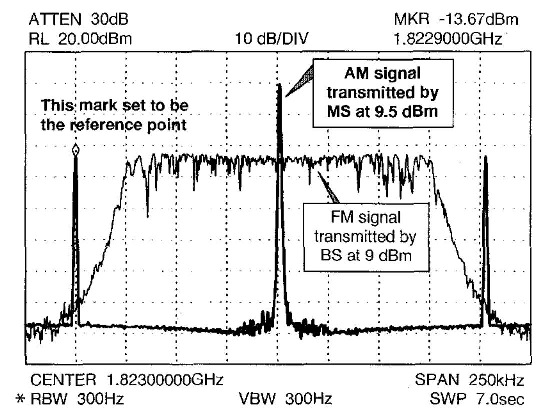

Fig. 2 *MS and BS transmitted signals in DFD transmission tests*

Experiment results: A prototype of DFD radio transceiver was implemented based on the architecture given in Fig. 1, but excluding the baseband adaptive echo canceller. The prototype system operated over a 200kHz radio channel centred at 1.823GHz. DFD transmission tests were conducted in the laboratory with the prototype working as a mobile station (MS). A three-tone AM signal as shown in Fig. 2 was transmitted by the MS, whose two side-tones were at the edges of the 200kHz channel bandwidth under test. The transmitted power at the antenna input was +9.5dBm. Cancellation levels were measured against the side-tone levels, however, it should be noted that the optimum cancellation levels are always higher in the band centre.

To ascertain the two-way transmission performance, an additional transmitter was enabled as a base station (BS). The distance between the MS and BS was in the range 5–20m with the BS transmitting a ramp-modulated FM signal, also shown in Fig. 2, so that any distortion at any frequencies within the band could easily be identified. This signal did not cover the entire 200kHz channel band, leaving ~25kHz at each side of the band, so that the signal level of the two side-tones was not masked by the BS signal, and was always visible during the measurements. The total BS signal power was +9dBm at the antenna feed point.

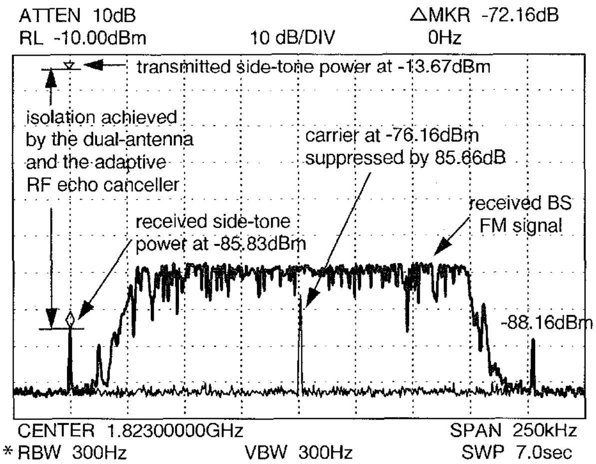

Fig. 3 *Signal spectra at DFD receiver input after isolation enhancement*

While both the MS and BS were transmitting, an overlapped spectrum was received at the DFD receiver. However, because the dual-antenna and adaptive RF echo canceller provided isolation enhancement, the locally transmitted signal was significantly suppressed by 72dB. The BS signal, on the other hand, only suffered a path loss of some 56dB with Fig. 3 showing the received spectrum at the DFD receiver input just after the RF echo canceller. Of the duplex isolation obtained, ~29dB was provided by the dual-antenna, 37dB by the RF echo canceller, and 6dB by the insertion loss of the subtractor and the directional coupler. Further, at the band centre, the isolation was measured at 86dB.

Conclusion: To alleviate the pressure on radio spectrum and system capacity issues in present and future wireless systems, division-free duplex is proposed for full-duplex radio transmission. Experimental results show that 72dB duplex isolation is achievable over the 200kHz radio channel by using a dual-antenna and an adaptive RF echo canceller. Further improvement in duplex isolation can be achieved if a baseband echo canceller is employed.

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