The threshold current $I_L$ is a function of length $L$ of the cavity and is given by

$$I_L = K(1/2 \ln (1/R_e R_s) + \sigma_{eff} L)$$  \hspace{1cm} (1)$$

where $K$ is a coefficient which is given by gain, the size of a laser diode, internal quantum efficiency, and a confinement factor; $\sigma_{eff}$ is an internal loss; $R_e$ and $R_s$ are the reflectivities of the etched and cleaved facets, respectively. We can evaluate cavity length and by using a typical value of 0.32 for $R_s$, the results are shown in Fig. 4. The reflectivity of the etched facet is $-6\%$. We can also determine the values of $K$ and $\sigma_{eff}$; these are 10.8 mA and 41.5 cm$^{-1}$, respectively.

![Fig. 4 Dependence of threshold current on laser cavity length](image)

The scattering loss $S$ of the etched facet is calculated from the ratio of external quantum efficiencies of the etched and the cleaved facets, which is expressed as

$$S = \frac{n_e}{n_t} \sqrt{\frac{R_e}{R_c}} \left(1 - \frac{R_c}{R_e} - S\right)$$  \hspace{1cm} (2)$$

where $n_t$ and $n_e$ are the external quantum efficiencies of the etched and cleaved facets. By substituting the measured value of $S$ of 0.99 and 0.06 for $n_t/n_e$ and $R_e/R_c$, respectively, and by using a value of 0.32 for $R_s$, again, the scattering loss is calculated to be 0.6.

Conclusion: A GaInAsP/InP mass transport laser diode monolithically integrated with a photodiode has been successfully fabricated by means of a reactive ion etching technique using ethane and hydrogen. The monitor photodiode shows a current response linearly proportional to the laser output power under an unbiased voltage. The threshold current of the laser diode and the responsivity of the photodiode were 57 mA and 0.24 A/W, respectively.

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References


900 MHz MULTIPATH PROPAGATION
MEASUREMENTS IN FOUR UNITED STATES CITIES

Indexing terms: Radiowave propagation, Mobile radio systems, Radiocommunication

This letter describes multipath power delay profile measurements of 900 MHz mobile radio channels in four US cities. Preliminary data show that for over 98% of the measured locations, RMS delay spreads are less than 12 μs. In very rare instances, reflections from city skylines and mountains can cause RMS delay spreads which exceed 20 μs and excess delays which exceed 100 μs. Such large excess delays have not been previously reported in the literature.

Introduction: To date, US cellular radio telephones have used strictly analogue voice transmissions with 30 kHz RF channel spacings in the 800/900 MHz band. Here we present initial results of propagation measurements made in four typical cellular radio markets throughout the United States. The measurements are necessary to determine viable multiple access techniques and equalisation requirements for next generation digital US cellular radio telephone systems. Digital cellular systems will gradually begin to replace existing US analogue systems in 1991.1

Measurements of multipath power delay profiles were made in Washington (DC), Greenbelt (MD), Oakland (CA), and San Francisco (CA). The measurements provided a sample of (local worst-case) multipath profiles from typical operating cellular markets.

Measurement apparatus: Fig. 1 is a block diagram of the measurement apparatus. The mobile transmitter is capable of generating 60 W pulsed and CW transmissions and is similar to a time-domain multipath measurement systems used to measure power delay profiles and narrowband fading in indoor radio channels.2 A 4 MHz RF spectrum centred at 892 MHz is used to transmit repetitively 500 ns RF pulses. The base station receiver front-end uses specially designed eight-stage cavity filters. A 70 dB low-noise amplifier chain with decade attenuator is used to adjust the received signal power to within the dynamic range of the square-law pulse detector. Profiles are measured and stored by a digital oscilloscope with an IEEE-488 interface to a portable computer. When compared with the back-to-back connection of transmitter and receiver, the system measurement range is 129–148 dB depending on receiver location and transmit power. Receiver dynamic range display is 30 dB. Receiving antennas in all four cities are 9 dB omnidirectional verticals which are located at existing cell sites.

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residential areas were studied. A total of about 6000 multipath delay profiles from the four cities were recorded over a wide range of terrain and vehicle speeds. These data are used to form conservative statistical models of RMS delay spread and excess delay spread (10 dB) in cellular mobile radio telephone channels.

An empirical/analytical technique is used to determine noise threshold. This technique is presently being used to interpret indoor multipath propagation inside factories, and assumes an average SNR of 10 dB across the measured profile. In References 3 it is shown that thresholding is important in the computation and interpretation of multipath delay spread. Our thresholding technique provides a multipath receiver sensitivity which is comparable to commercial cellular radio-telephones when compared on a per-bandwidth basis.

Data: Fig. 2 shows a typical power delay profile measured in Washington DC. Multipath arrives continuously over several microseconds. The profiles are recorded as discrete displays on the digital oscilloscope with sampling intervals which are integer multiples of 40 ns. To determine the peak power over a particular excess delay interval, one merely sums the power contribution over the necessary number of discrete points. The power in the first arriving pulse is found by integrating the received power over the first 500 ns excess delay. The horizontal line on the plot indicates the noise threshold.

RMS delay spreads in Washington DC, and Oakland CA are typically less than 2 or 3 μs for urban areas, with larger values arising when the mobile is on bridges or overpasses. This result is intuitive, as large buildings serve to confine RF energy along city blocks while shadowing potential multipath signals from outlying reflecting objects. When mobiles are on bridges and overpasses, or are located in residential areas, propagation is less confined by surrounding buildings. In these open areas, the data indicate greater delay spreads can result when surrounding terrain is mountainous.

Fig. 3 is a worst-case measurement made in south San Francisco in a mountainous/hilly region, and shows that multipath components can have excess delays as large as 100 μs. This implies a 30 km excess round trip travel distance for some multipath signals. The case of 100 μs excess delays appears to be quite rare, as it has not been reported before in the literature. The Mansell Street hill is an unusual location since the mobile has line-of-sight to the San Francisco skyline, Oakland skyline, San Bruno Mountains, Mount Davidson, Golden Gate Bridge, and the Bay Bridge. These potential reflectors induce excess delays of approximately 50 μs, 100 μs, 35 μs, 20 μs, 80 μs, 55 μs, and 90 μs, respectively. The direct path between base and mobile is partially obstructed by McLaren Park. Fig. 3 shows that all of these scatterers are represented in the received multipath profile. Worst-case RMS delay spreads ranged between 10 to 25 μs at this location.

Because mobile radio channels on the east coast (where there are fewer mountains) appear to be less dispersive than channels in the San Francisco/Oakland area, less measurements were made in Washington and Greenbelt. Table 1 shows the probabilities that a multipath component will be within 10 dB of the strongest component for a specified excess delay for different cities. Approximately 12% of the Washington DC measurements and 6% of the Greenbelt measurements had worst-case excess delays of about 20 μs. Multipath within 10 dB of the first arriving signal was not observed at excess delays greater than 19.5 μs at these east coast locations. However, the west coast channels were found to have excess delays (10 dB) which exceed 20 or 30 μs. In San Francisco, where measurements were made in a mountainous region approximately 10 km south of the metropolitan area, multipath power was within 10 dB of the main signal at 48 μs excess delay for 1% of the measured locations.

Table 2 shows the likelihood that a particular value of RMS delay spread will be exceeded for different cities. Table 2 shows that east coast channels will have RMS delay spreads which rarely exceed 7.5 μs, whereas west coast channels have RMS delay spreads which exceed 20 μs.
Recent work has shown that the ratio of RMS delay spread to symbol duration in a digital radio channel must be kept below 0.2 or 0.3. Assuming a 40kbit per second data rate with DQPSK modulation and a critical $(\sigma/\tau)$ value of 0.25, the maximum tolerable $(\sigma/\tau)$ value is 12.5. At RMS delay spreads larger than this, equalisation is required. Based on our data, the critical RMS delay spread is exceeded at 19% of all measured locations.

Since all measurements represented in the Tables have concentrated on local worst-case situations, it stands to reason that next generation US digital cellular systems will encounter somewhat tamer channels than are portrayed here. Our data shows that in many cities where terrain is flat (such as Washington or Greenbelt), RMS delay spreads do not exceed 7 or 8μs. In urban areas with surrounding hills, such as Oakland, RMS delay spreads do not exceed 15μs. These conclusions are similar to European measurements which indicate RMS delay spreads larger than 7 or 8μs are usually not seen, except for in mountainous regions.

Only at locations like Mansell Street in San Francisco, where unusually large scatterers are illuminated (mountains and bridges) and LOS paths are shadowed, do RMS delay spreads exceed 15μs. It is clear that in these rare locations, either service will have to be sacrificed or special precautions will be required to mitigate intersymbol and cochannel interference.

Conclusion: About 6000 local worst-case power delay profile measurements were made at 900 MHz in four US cities. These data have been obtained at local worst-case locations, and form the basis for statistical models which can be used to predict the percentage of locations which will experience particular values of RMS delay spread and excess delay spread (10μs down). Worst-case time dispersion can exceed 100μs in mountainous areas, although this is rare. In the four cities measured, RMS delay spread rarely exceeds 13μs. However, in cities such as Salt Lake City or Denver, where mountains are visible to many downtown locations, delay spread statistics could be different.

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References

SURFACE-ACOUSTIC-WAVE UNIDIRECTIONAL TRANSDUCERS USING ANODIC OXIDATION TECHNOLOGY AND LOW-LOSS FILTERS

Indexing terms: Ultrasonics, Surface-acoustic-wave devices, SAWs, Transducers

A new surface-acoustic-wave interdigital transducer (IDT) and unidirectional transducer (UDT) are described. Using a lift-off anodic oxidation method, controllable gaps between electrodes with good insulation can be obtained. Experimental results show good characteristics at 2nd-harmonic operation for a new floating electrode type unidirectional transducer (NG-FEUDT) and a new floating electrode type unidirectional transducer (NG-FEUDT) for fundamental and 2nd-harmonic operation. These can be made to increase the operating frequency.

New structures and principles of operation: The interdigital width of a conventional IDT (CIDT) with a line and space ratio of 1:1 is λ/4 (λ = wavelength at centre frequency $f_0$). In contrast, the wide electrode width of the NG-CIDT shown in Fig. 1a is about $2/2$, and the operating frequency is twice that of a CIDT under the condition of the same width of the photomask. The operating frequency of the NG-CIDT can, therefore, be increased, and the electrode resistance is reduced to about half that of a CIDT. Similarly to the case of the double electrode, the reflections from electrodes due to the mass loading effect can cancel each other. So, the triple transit echo (TTE) is reduced.

Fig. 1b shows one example of a new NG-FEUDT with a floating open electrode. In this case, the minimum width of the electrodes is about $2/5$, which is much wider than the $2/10$ of the old FEUDT. Therefore, UDTS of higher frequencies are possible using NG-FEUDT techniques. Also, 2nd-harmonic operation results give a large directivity and a large radiation conductance.

![Fig. 1 Comparatively narrow gap interdigital transducer (NG-IDT)](image-url)