Simulating Signal Propagation Effects of the Mobile Radio

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Abstract – The ability to simulate various mobile radio channel impairments, particularly, multipath fading, in the products design phase, before equalizer algorithms have been implemented as custom ASICs, is critical. This paper presents the test procedure, developed for type-approval testing of a multipath fading simulator, as well as corresponding practical measurement results in terms of spurious signals and intermodulation products, transfer functions, amplitude statistics, Doppler spectra, delay power profiles, and impulse responses, which can be used as a reference in similar situations.

1. Introduction

Signal conditions at the vehicle antenna of a mobile cellular telephone receiver are among the worst that a radio circuit design engineer will ever encounter.

Typically, the radio circuit designer provides protection from the various signal impairments with adaptive equalizers and other compensations such as AGC circuits and error correcting codes. These can often overcome the expected signal deteriorations arising from Doppler frequency shifts, multipath signals and other effects.

The ability to simulate all various impairments, singly or in combination, at the design phase, before equalizer algorithms have been implemented as custom ASICs, is critical.

In this paper, measurements specifications of various types of signal impairments, seen in a real world mobile radio environment, are investigated for a test signal from a particular RF channel simulator test instrument (namely HP 11759C), featuring:

-attenuation to account to path loss due to distance

-slow fading with a log-normal distribution

-fast fading with a Rayleigh distribution

-random FM caused by vehicle motion (Doppler)

-multiple paths with an adjustable delay difference,

and so determining the measurement accuracy and applicability of such testing to various cellular radios.

Specifically, these investigations were developed and accomplished by the company Hewlett-Packard (now Agilent Technologies*) as acceptance tests within the project for the TurkCell company, a major cell operator in Turkey.

The reference source for the implementation of Doppler spectra and GSM standard profiles was GSM Rec. 05.05, Annex 3.

2. Multipath Fading Simulator

HP 11759C is a wideband multipath mobile radio channel simulator. It can support 12 taps in two separate boxes. Each box can be ordered as a standard unit with 2 RF channels, each with 3 taps, or, optionally, with 1 RF channel containing 6 taps.

A simplified block diagram for one unit of the HP 11759C is shown in *Fig. 1*. The RF input signal is down converted to the IF range of 6 MHz and split into 6 paths. In each path the signal is delayed by a digital unit, using 12-bit A/D and D/A converters.

Noise sequences generating the fading of the transmitted signals are modulated by analog quadrature modulators in each tap.

Attenuated signals from each path are combined and finally up converted to the RF range. The fading simulator HP 11759C is designed for use in a wide frequency range with a bandwidth of 6 MHz. The center frequency can be set between 40 and 2700 MHz by adjustment of the frequency of the external local oscillator. It must be set 6 MHz above or below the wanted center radio frequency.

The delay of each tap can be set in steps of 50 ns (optional 1 ns) in the range of 0 to 186 us.

Attenuation can be set in the range of 0-50 dB in steps of 0.1 dB.

Maximum Doppler frequency is 425 Hz.

Noise spectra can be Classical Doppler and Pure Doppler shift according to GSM Rec. 05.05 Annex 3.

There is a program IQMAKE to generate noise sequences for Rayleigh distributed magnitudes with specified Doppler spectra, as well as for the generation of noise sequences having Rician or other distributions of the magnitude. Ten user-defined profiles can be saved and recalled by menu.

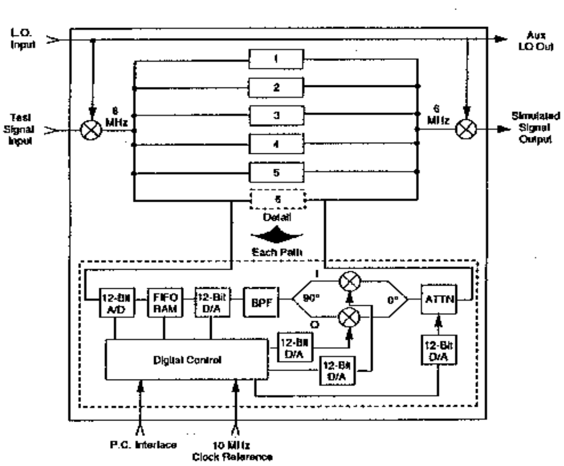

Fig.1 Multipath fading simulator HP 11 759C

To complete the simulation equipment, two other system devices were necessary: a computer acting as a front panel/controller for the HP 11759C, and a Local Oscillator, used to determine the RF operating frequency and to supply a l0 MHz timebase.

3. Spurious Signals and Intermodulation

Additional equipment used for these tests on the HP 11759C included Rohde&Schwarz signal generators: SMHU, and two SMGU for the RF-input signals and for the local oscillator. The output was measured with a Rohde&Schwarz spectrum and network analyzer FSBS.

3.1 Spurious Signals

Tests of spurious signals were performed in different modes of operation, with different frequency spans and on different taps. An example of these measurements is presented by *Fig.3.1*. The spurious signals are suppressed by more than 64 dB. There is no suppression of the LO component at the output of the fading simulator, which yields a higher level of the LO signal compared to the wanted signal and its mirror. Spurious signals outside the bandwidth of the simulator are at least 47dB below the level of the test signal. For the frequency span between 0 and 3 GHz with no input signal at the simulator, the frequency of the LO was set to 444 MHz.

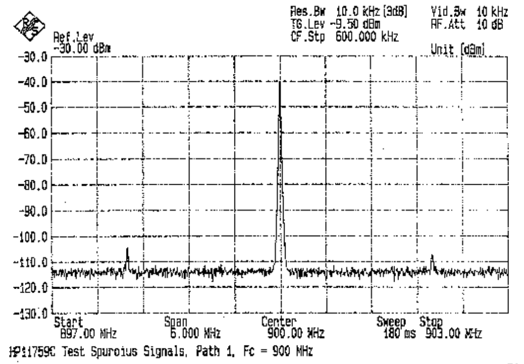

Fig.3.1 Spurious signal at 900 MHz input signal, RF input in the range 897-903 MHz, LO=894 MHz

In this case, the received spectrum at the output of the simulator consists of the LO feed-through and its first harmonics. No other spurious signals were observed.

3.2 Intermodulation Products

Fig.3.2 presents the intermodulation products when the input to the simulator were two CW signals of 900.0 MHz and 901.0 MHz, combined through a 3 dB power combiner. The input signal level was adjusted so that the power overload indicator was just turned off. Some informal tests were also performed using higher signal levels. The measurements were made within a frequency band of 10 MHz.

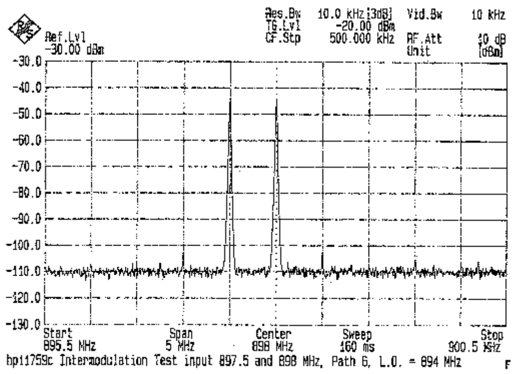

Fig.3.2 Intermodulation products of two CW signals at 900 and 901 MHz at RF input

Generally, the intermodulation products are suppressed by 58 dB with respect to the input signal levels.

4. Transfer Functions

The magnitude of the transfer functions was measured using the spectrum analyzer Rhode&Schwarz FSBS. The magnitude, phase and group delay were measured by means of the network analyzer Hewlett-Packard HP 8510.

An example of the magnitude of the transfer functions applying FSBS is depicted in *Fig.4.1*, with frequency span of 30 MHz and amplitude resolution of 10 dB/Div. That particular measurement was made with the input signal at 910 MHz (LO = 904 MHz). It can be seen, that there is no filtering of the LO and image frequencies of the transmission band at the output of the simulator.

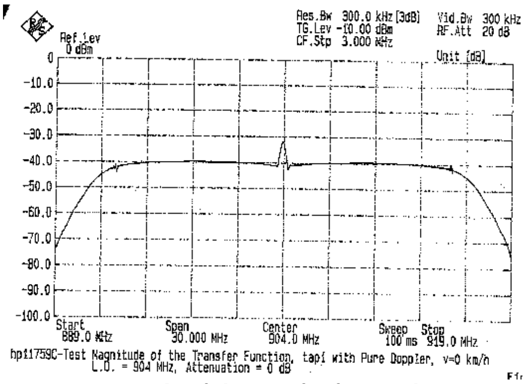

Fig.4.1 Magnitude of the transfer function between RF input and RF output for a frequency span of 30 MHz

Furthermore, for the input signal at 900 MHz (LO = 894 MHz), corresponding to the bandwidth of the fading simulator, the magnitude was found to deviate by less than 0.7 dB. The deviation for the taps of box B was in all cases less than 0.5 dB. Only tap 6 shows a slightly larger deviation than the other taps in box A. There is a good correspondence for the taps of box B, whereas for the taps of box A the output level differs by 0.5 dB. The levels at outputs of boxes A and B were found to differ by 1 dB because of separate up converters and radio frequency amplifiers. The observation of the transfer function at low speeds revealed no variations of the transfer functions. The measurements of the transfer function were performed in stop mode with Pure Doppler shift. When a Rayleigh spectrum at 0 Hz is selected, all the I/Q modulators are set to a magnitude equal to the average magnitude of the Rayleigh spectrum. The phase is set to 45 degrees.

Magnitude, phase and group delay of the transfer function were measured with the network analyzer HP 8510. Magnitude and phase are depicted in *Fig.4.2*, while magnitude and group delay are plotted in *Fig.4.3*, with one tap being used in each case.

The peak-to-peak deviation of the phase is about 7 degrees and the variation of the group delay is about 30 ns within the bandwidth of the simulator. *Fig.4.4* shows the magnitude of the transfer function, which was achieved when two taps with equal levels were superimposed. The delay difference was l us.

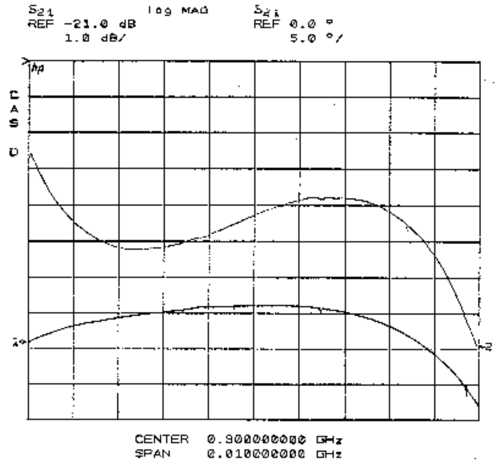

Fig.4.2 Magnitude and phase of the transfer function between RFin and RFout for frequency span of 10 MHz

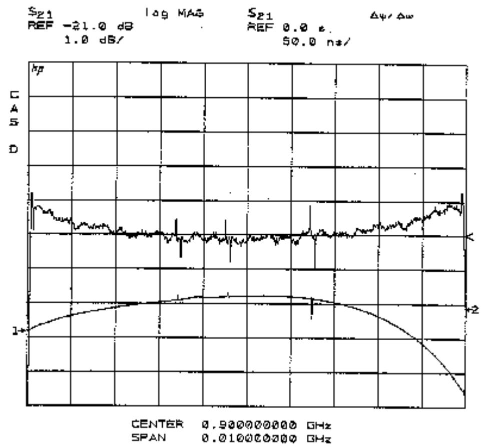

Fig.4.3 Magnitude and group delay of the transfer function between RFin and RFout for frequency span of 10 MHz

Since the magnitudes of the transfer functions are frequency dependent and vary from tap to tap, the depth of the deep fades changes with frequency. This difference, however, appears only in static operation, which was used to plot the graph in *Fig.4.4*.

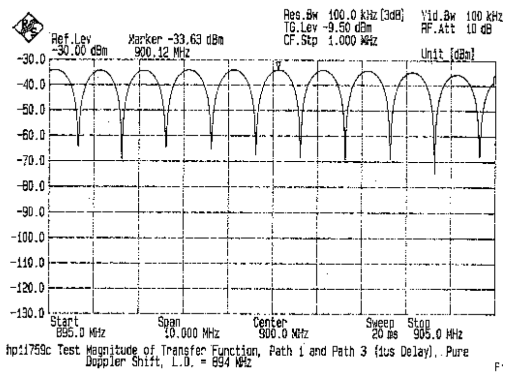

Fig.4.4 Magnitude of the transfer function between RF input and RF output for a two-tap model with equal magnitudes and delays differing by 1 us

In dynamic operation *H(f,t)* simulates deep fades evenly distributed at all frequencies. Therefore, the different fade depths shown in *Fig.4.4* have no impact on the performance of HP 11759C. Measurement using the network analyzer HP 8510 to determine magnitude and group delay versus frequency, is represented in *Fig.4.5* for equal magnitudes and in *Fig.4.6* for 1 dB level difference for both taps, respectively.

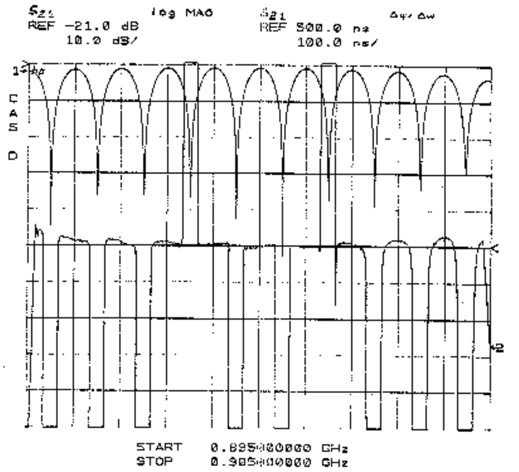

Fig.4.5 Magnitude and group delay of the transfer function between RF input and RF output A for a two-tap model with equal magnitudes and delays differing by 1 us

Fig.4.5 shows peaks of the group delay varying randomly through positive and negative values. The negative values represent minimum phase filters and the positive peaks reveal non-minimum phase filters. The plot shows that the values of the magnitudes of transfer functions in both taps differ only by a very small amount and cross several times within the frequency span.

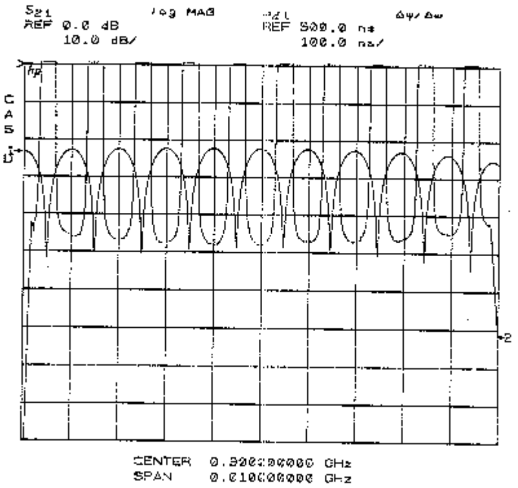

Fig.4.6 Magnitude and group delay of the transfer function between RF input and RF output A for a two-tap model with magnitudes differing by 1 dB and delays differing by 1 us

In *Fig.4.6*, the magnitude of the transfer function of the tap with 1 us delay was reduced by 1 dB. In this case, all peaks of the group delay reveal maximum phase state. The fade depths vary within the given frequency band and have a value of more than 27 dB compared to the value of 25 dB, which results for a difference of exactly 1 dB between the levels of both paths.

Magnitude and group delay of a two-path model with a difference of 31 dB are depicted in *Fig.4.7*.

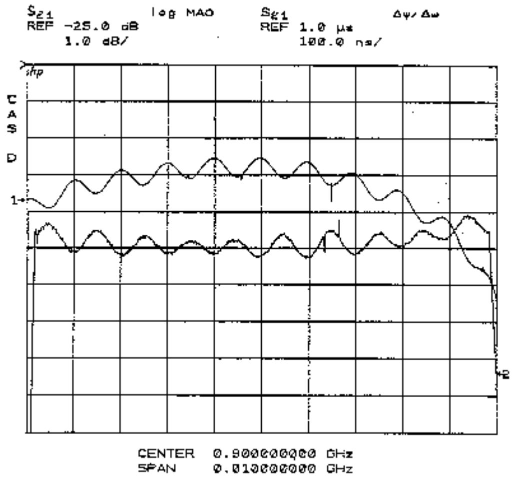

Fig.4.7 Magnitude and group delay of the transfer funct. between RF input and RF output A for a two-tap model with magnitudes and delays differing by 31 dB and 1 us

Variation of the magnitude, with respect to the superimposition of the transfer function, nearly comes up to the value of 0.5 dB, which results for a two-path model with a difference of 31 dB. The peak-to-peak variation of the group delay is about 80 ns. These results demonstrate that the calibration of the delays is achieved well by HP 11759C. This calibration has also been tested in the time domain (pulse responses, described in section 8).

5. Amplitude Statistics

The set-up for measurements of the amplitude statistics is shown in *Fig.5.1*.

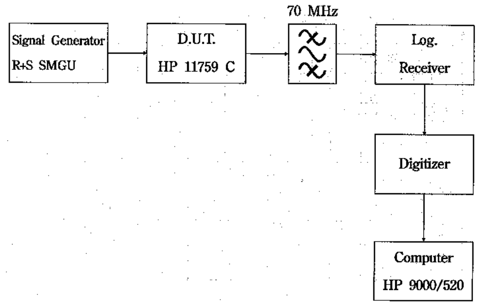

Fig.5.1 Set up for amplitude statistics measurements

It consists of a signal generator providing a CW signal for the HP 11759C fading simulator and a measuring receiver connected to a digitizer and a computer. At the output of the simulator a bandpass filter with 70 MHz central frequency was used to suppress the unwanted signals.
A specified number of samples, in this case 3x8192, was taken from the output of the receiver and classified in the computer. The sampling interval was 50 ms and the frequency of the test signal was 70 MHz.
The cumulative distribution functions (cdfs) measured are plotted in *Fig.5.2*, including:

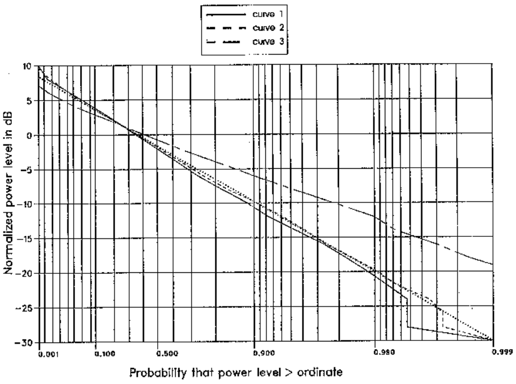

Fig.5.2 Cumulative distribution functions measured in one tap (dotted: Rayleighian)

-classical Doppler spectrum on path 1 at 38.5 km/h (curve 1), *f_D = 2.5Hz → 3km/h* in GSM
-classical Doppler spectrum on path 1 at 411.7 km/h (curve 2), *f_D = 26.7Hz → 32km/h* in GSM
-Pure Doppler shift on path 1 with the attenuation of 11.5 dB and classical Doppler spectrum on path 2 with the attenuation of 7 .6 dB (curve 3)
The cdfs are plotted in probability paper in which Weibull distributions result in straight lines. The Rayleigh distribution is a special case of the Weibull distribution characterized theoretically by a level difference of 13.4 dB between the first and ninth decentile of the cdf. For curve 1, this value is 14.9 dB, so the curve of the measured distribution, which should be Rayleigh, is too steep compared to the theoretical shape. This means that deep fades will happen more often. The standard deviation of the measured fading was s = 5.93 dB instead of 5.57 dB, which is the theoretical value of this Rayleigh distribution.
The curve 2 was measured with the Classical Doppler spectrum at a simulated speed of 411.7 km/h. The level difference between the first and ninth decentile is almost 13.4 dB and the plotted curve coincide well with the theoretical shape. The standard deviation of this curve was 5.61 dB. The curve 3 reveals amplitude distributions that are described by the Rician probability density function. The standard deviation of curve 3 was s = 3.66 dB.

6. Doppler Spectra

Doppler spectra. were measured with a. CW signal at the input of the simulator and with one tap active, except the case, where a Rice spectrum was obtained by using two taps. Therefore, two different noise types can be used: Classical Doppler and Pure Doppler shift.

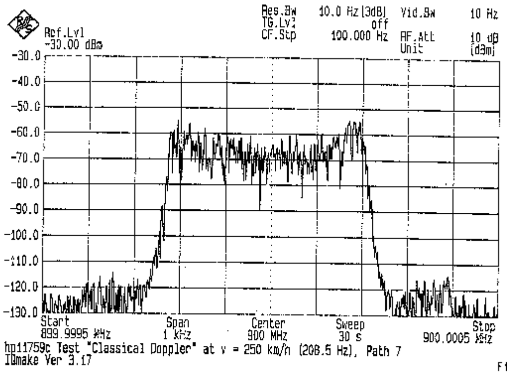

Fig.6.1 Classical Doppler spectrum at 250 km/h

The classical Doppler spectrum at 250 km/h is depicted in *Fig.6.1*, and the Pure Doppler shift at 250 km/h, is shown in *Fig.6.2*.

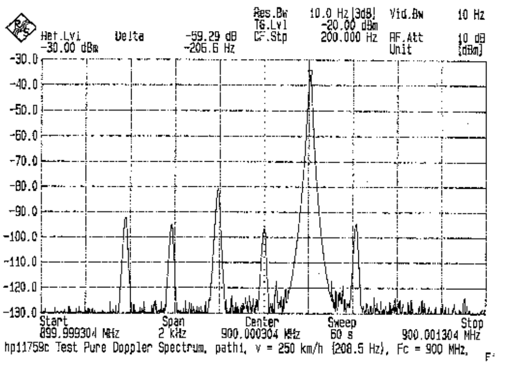

Fig.6.2 Pure Doppler shift at 250 km/h

The suppression of the carrier signal is 59 dB and of the image is more than 40 dB.

7. Delay Power Profiles

The delays and amplitudes assigned to the taps of the HP11759C followed the predefined delay power profiles [3]. Two alternatives of profile tables are valid for official GSM mobile-station type-approval procedures, and are both implemented in the HP 11759C.

8. Impulse Responses

A block diagram of the measurement setup is shown in *Fig.8.1*.

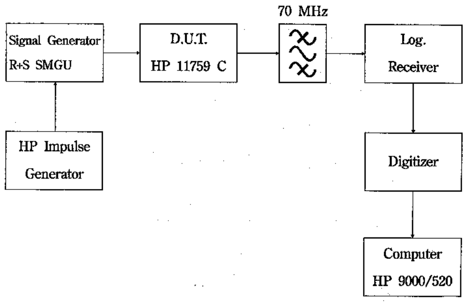

Fig.8.1 Set up for amplitude statistics measurements

It consists of an impulse generator and a signal generator providing the input signal for the fading simulator, the fading simulator HP 11759C, and finally a measuring receiver connected to a digitizer and a computer.
The 70 MHz band pass filter between the output of the simulator and the digitizer has a. bandwidth of 6 MHz and an insertion loss of 5 dB. For 12 tap settings the output and input of the two boxes have to be connected by a power combiner and power divider, which results in additional losses. All the measurements have been performed using the averaging function of the oscilloscope to remove any noise and to show average values instead of instantaneous values.
The accuracy of timing for different paths was verified by means of the impulse response. All paths were found to be positioned within the resolution of the oscilloscope itself. The accuracy of the amplitudes between different taps was found to be better than 1.0 dB.
Different recommended impulse responses were generated, for rural area, typical urban area (*Fig.8.2*) and hilly terrain.

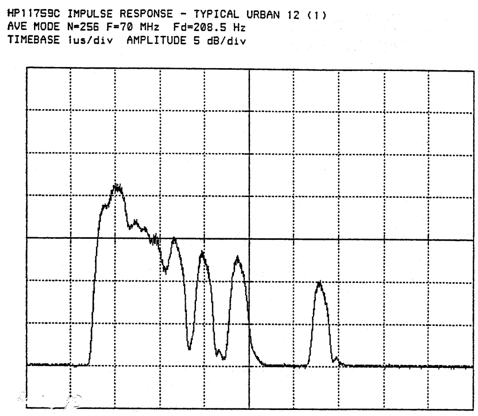

Fig.8.2 Envelope of the impulse response for simulation in typical urban areas using 12 taps

Comparison of different impulse responses shows that serious simplifications of
the delay power profiles result from reducing 12 taps to 6 ones.

9. Conclusions

The performed tests and measurements revealed the following general results:
-Overall, the simulator showed a very good performance.
-The spurious signals and intermodulation products within the specified bandwidth of the simulator are suppressed by at least 59 dB.
-The phases of the transfer function and the group delay distortion within the individual taps are less than 7 degrees and 30 ns, respectively.
-There is no suppression of the LO feed through and the mirror frequency of the wanted signal.
-The calibration of the delays, checked by two different methods, was found to be very accurate.
-Measurements in time domain showed a poor tap-to-tap attenuation matching, whereas, in frequency domain, there is a good correspondence between each tap of one box.
-Comparing the output of the two boxes showed a mismatch of 1 dB. When two boxes are combined for 12 tap settings, calibration is necessary.
-The amplitude statistics was proved to be Rayleigh distributed for Doppler spectra. For lower simulated speeds, the distribution deviates slightly from the Rayleighian distribution. Rician distributions can also be simulated by superimposing classical Doppler and pure Doppler shift.
-Two taps of the simulator are used to simulate Rician distributions.
-The measurements in time domain revealed a high signal-to-noise ratio, taking into account additional losses of the measuring equipment.
-The frequency of the Local Oscillator is close to the transmission band and there is no filtering at the output of the simulator. Hence, this can cause problems when using non-frequency selective devices.

4. References

[1] V.Lipovac and A.Sertic, “Developing Test Methods for Installation and Maintenance of GSM Base Stations”, Proc. 11th Seminar and Exhibition on Telecommunication and Information Networks, pp.195-204, Keszthely, October 1998
[2] ETSI, “GSM 11.20 Specification”
[3] ETSI, “GSM Rec.05.05, Annex 3”
[4] Hewlett_Packard, “RF Multipath Fading Simulator HP 11 759C”, Operation Manual and Service Manual, January 1998.