2-GHz Band Man-Made Noise Evaluation for Cryogenic Receiver Front-End

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Abstract. This paper presents measured results of man-made noise in urban and suburban areas in the 2-GHz band with amplitude probability distribution (APD) in order to evaluate the impact of man-made noise on an experimental cryogenic receiver front-end (CRFE). The CRFE comprises a high-temperature superconducting filter, cryogenically-cooled low-noise amplifier, and highly reliable cryostat that is very compact. The CRFE is anticipated to be an effective way to achieve efficient frequency utilization and to improve the sensitivity of mobile base station receivers. It is important to measure the characteristics of the man-made noise in typical cellular base station antenna environments and confirm their impact on the CRFE reception with APD because if man-made noise has a stronger effect than thermal noise, the CRFE would fail to offer any improvement in sensitivity. The measured results suggest that the contribution of man-made noise in the 2-GHz band can be ignored as far as the wideband code division multiple access (W-CDMA) system is concerned.

1. Introduction

Mobile phones are now coming into wide use as an important means of communications. Mobile services provided through mobile phones have been enhanced and improved to cope with diversifying user needs. The frequency bands used in mobile phones have become increasingly higher with the growing demand for high-speed and high-capacity data transmission. It is important to improve the sensitivity of a base station receiver system since the propagation and feeder losses increase as the frequency band becomes higher. Achieving extremely low-noise and high gain characteristics is the technical key for improving the sensitivity of the base station receiver system. It is also important for the base station receiver system to have high selectivity from the standpoint of efficient frequency utilization. This is because the frequency bands used by mobile communication system operators should be assigned as closely as possible without interfering with each other. Employing a very sharp-skirt receiving bandpass filter is one of the effective and practical approaches to suppressing the interference from the signals in adjacent bands, which can also reduce the saturation power level required for the low-noise amplifier used in the base station receiver system. A cryogenic receiver
front-end (CRFE), comprising a high temperature superconducting filter (HTSF), cryogenically-cooled low-noise amplifier (CLNA), and highly reliable compact-sized cryostat, has been proposed as a powerful candidate to achieve efficient frequency utilization and high sensitivity performance for mobile base station receivers [1-4].

Here, sensitivity represents the minimum received signal power level required to establish successfully a radio communication link between the mobile station and base station. Therefore, thermal noise must be evaluated because sensitivity increases as the thermal noise is reduced. Our previous investigations [3, 4] showed that sensitivity improvements of up to 3 dB can be achieved by employing an antenna of small ohmic loss and a very low noise CRFE based on the equivalent noise temperature [5], which is an index for evaluating the thermal noise.

In addition to the thermal noise, it is important to measure the characteristics of man-made noise in typical cellular base station antenna environments and confirm their impact on the CRFE reception because if man-made noise has a stronger effect thanthermal noise, the CRFE would fail to offer any improvement in sensitivity. The amplitude probability distribution (APD) method [6], which provides amplitude distribution analysis data for the antenna noise envelope, is useful in estimating the impact of man-made noise such as impulsive noise, lightning pulses, or interference on the received signals. There were reports on measurement results of impulsive noise pertaining to the electromagnetic environment for the universal mobile telecommunication system (UMTS) by using a receiver front-end (RFE) that comprised a normal temperature bandpass filter and normal temperature low-noise amplifier [7] or pertaining to the radio environment of mobile base stations [8].

This paper shows the measured results of man-made noise in urban and suburban areas for the 2-GHz band by applying the APD method. The measured results show that the influence of man-made noise can be ignored as far as the W-CDMA system is concerned.

2. Configuration of cryogenic receiver front-end and measurement system

2.1. Cryogenic receiver front-end

Figure 1 shows an example of an existing tower-mounted receiver front-end (RFE). Similar to this RFE, the CRFE should be lightweight, small, and highly reliable to offer easy installation and maintenance because it is to be installed in the vicinity of the antenna or to be mounted on a tower to maximize reception sensitivity of the base station receiver system. Figure 2 shows the fundamental configuration of the CRFE. A modified duplexer is inserted in front of the HTSF in order to use the same antenna for simultaneous reception and transmission. The out-of-band attenuation of the
receiving band of the modified duplexer is not as large as that of the conventional one used in the existing RFE since the following HTSF provides sufficient performance as a receiving band pass filter.

2.2. Amplitude probability distribution

In this paper, the APD is defined as the percentage of time during which the impulsive signal envelope exceeds a certain threshold level. As shown in figure 3(a), if the measured signal envelope exceeds a certain threshold level, $a_p$ at $t_1$, $\cdots$, $t_{N-1}$, $t_N$ during the time interval $T$, the APD is given as

$$APD = \frac{\sum_{k=1}^{N} t_k}{T}.$$  \hspace{1cm} (1)

Figure 3(b) shows an example of the APD.

2.3. Measurement system

Figure 4 shows the configuration of the APD measurement experiment. Figure 5 presents an RF performance of the CRFE used in this experiment. All characteristics were measured at 70 K. The CRFE has a center frequency of 1.95 GHz, a passband width of 20 MHz, and a sharp skirt characteristic of 20 dB/100 kHz. The average passband gain and average equivalent noise temperature are 31.3 dB and 47.9 K, respectively. The target noise is measured at center frequency $f_c$ of the spectrum analyzer in the zero-span mode. The intermediate frequency (IF) bandwidth, which corresponds to the resolution bandwidth (RBW) of the spectrum analyzer, must be set sufficiently wide when evaluating the instantaneous value of noise because it is difficult to observe the influence

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**Figure 3.** Definition of APD.

**Figure 4.** Configuration of APD measurement experiment.
of the man-made noise if the IF bandwidth is too narrow. In other words, it is ideal to measure noise with the IF bandwidth of a specific signal when evaluating the influence of noise on that specific signal. Thus, the noise waveform observed for specific frequency $f_c$ is derived from the video output port of the spectrum analyzer.

As shown in figure 6(a), the noise waveform is sampled at a sampling frequency of 20 MHz and

![Figure 6](image)

(a) Frequency characteristics. (b) Equivalent noise temperature and gain.

**Figure 5.** RF performance of CRFE measured at 70 K.

As shown in figure 6(a), the noise waveform is sampled at a sampling frequency of 20 MHz and

![Figure 6](image)

(a) Sampled noise waveform. (b) Noise amplitude level (NAL) evaluation.

Figure 6. Statistical process using APD measurement equipment.
digitized by an 8-bit A/D converter. The waveform is measured for one second, and subsequently the number of times is summarized for each value from 0 to 255 of the noise amplitude. This is performed as shown in figure 6(b). First, array variable \( m[k] \) \((0 \leq k \leq 255)\) is prepared and \( m[k] \) is set to 0 for all \( k \). Next, the digitized noise amplitude level (NAL) is evaluated for each sample, and one is added to the array variable of the array number corresponding to the NAL. If the NAL is \( k \) for a certain sample, then

\[
m[k] = m[k] + 1.
\]  

This one-second measurement yields a histogram where horizontal and vertical axes serve as level (array index \( k \)) and counts (array value \( m[k] \)), respectively, as shown in figure 6(c). After outputting these array values to a file, they are all reset to 0 and the next one-second measurement is performed. This process is repeated for a pre-determined time interval. Thus, as shown in figure 6(d), if \( M[i] \) represents the total number where the noise amplitude becomes \( i \), the APD to threshold level \( a \), \( APD[a] \), is given as

\[
APD[a] = \frac{\sum_{i=a}^{255} M[i]}{\sum_{i=0}^{255} M[i]}
\]  

3. Measurement results

In this experiment, center frequency \( f_c \) of the spectrum analyzer in figure 4 is set to 1.949 GHz after spectrum observation of the passband width of the CRFE to avoid specific frequencies that may be used by other communication systems. The antenna in figure 4 is a co-linear array antenna that has a 60-degree beamwidth in the horizontal plane and a 5-degree beamwidth in the vertical plane, as shown in figure 7. Zero- and six-degree beam tilt angles are used for the measurement. The measuring time interval is 1 h in the evening for each beam tilt angle. The antenna height is approximately 70 m in the suburban area, and approximately 100 m in the urban area. The IF bandwidth is set to 1 MHz because the upper limit of the spectrum analyzer used in this experiment is 1 MHz, although the IF bandwidth of the W-CDMA system is 3.84 MHz [9].

Figure 8 shows some typical APD data for the 2-GHz band in the urban and suburban areas. In the figure, the APD, which was measured by connecting a 290 K terminator to the input port of the CRFE, is also plotted in order to determine the thermal noise level. The reference point of the abscissa in figure 8 is the minimum value of the noise envelope derived by connecting the 290 K terminator. The APD data for the antenna noise almost coincide with those of the thermal noise at probabilities higher than \( 10^{-4} \). This shows that thermal noise is dominant above while man-made noise is dominant below the probability of \( 10^{-4} \).

Here, the following two assumptions are employed to conduct a rough but fundamental estimation of the influence of the received noise on the W-CDMA system: (1) The APD value is an indicator of the bit error rate (BER) measured in front of the detector. This is because instantaneous bit error might be caused when the instantaneous noise power exceeds the threshold level signifying error. (2) Although the IF bandwidth for the W-CDMA system is 3.84 MHz, the difference between 3.84 MHz and 1 MHz (used in this experiment) is inconsequential with regard to the APD characteristics.

From figure 8, the major noise at the corresponding amplitude probability distribution of \( 10^{-3} \) is thermal noise since the W-CDMA system employs very strong error correction techniques and therefore requires a minimum BER of approximately \( 10^{-3} \) for both voice and data. This suggests that the influence of man-made noise can be ignored as far as the W-CDMA system is concerned and sensitivity improvement offered by the CRFE will be attained.
4. Conclusion
This paper presented measured results of man-made noise in urban and suburban areas for the 2-GHz band using the APD method in typical cellular base station antenna environments from the standpoint of improving the sensitivity by employing the CRFE. Experimental results showed that the contribution of man-made noise can be ignored as far as the W-CDMA system is concerned. There is still need for measuring man-made noise in long time intervals for the purpose of seasonal factor analysis.

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Figure 7. Example of experimental environment in 2-GHz band.

Figure 8. APD of antenna noise measured in 2-GHz band.