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A Novel Multi-carrier Radar for High-speed Wide-bandwidth Stepped-Frequency GPR

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Ground Penetrating Radar (GPR) is one of the non-destructive testing methods for studying underground situations by using the electro-magnetic wave radiation effect. Two classical sensing techniques, impulsive GPR and stepped-frequency GPR, are used for a long time in various GPR applications. Signal bandwidths generated by the two techniques ranges from several hundred MHz to several GHz. For the research area of pavement survey the surveying speed is emphasized, thus impulsive GPR has been preferred to stepped-frequency GPR. To make a complete single scan operation, stepped-frequency GPR needs over hundreds of different frequency continuous wave (CW) radiations within its signal bandwidth which is the main time taking process. In case of impulsive GPR, it needs also several repeated pulses, for example from 64 to 512 repeated pulses, to do a complete single scan operation. Although the two techniques need several repeated internal operation processes, impulsive GPR is generally considered to be fast than stepped-frequency GPR. On the other hand, many studies of stepped-frequency GPR emphasizes that high-resolution scanning accuracy can be achieved by controlling each frequency component differently, such as frequency power profile, flexible bandwidth control.
In case of pavement survey area, high-accuracy scanning is required within one meter deep as well as high-speed survey. The required accuracy is up to several centimeter in the material where dielectric constant is about 10. When surveying pavement, multi-element array antenna gives advantages to the measurement accuracy enhancement, where the scanning region of a 3 meters wide paved road is divided into several sub-regions as the number of the antenna element. For example, when stepped-frequency GPR requires 6msec for single scan operation and 15-element antenna is considered, the survey speed is limited to 15km/h in order to scan the road every 5cm, which is slow compared with common driving condition on the paved road. To make it fast, the frequency step or the dwell time can be varied. But, increasing the frequency step affects the scanning time range performance, and decreasing the dwell time reduces SNR. In this paper, we introduce a novel multi-carrier radar technique, the step frequency multi-carrier (SFMC) which sends multiple CW signals simultaneously to speed up the scanning operation, where no reduction of the frequency step and the dwell time is required. In this paper, we apply the orthogonal frequency division multiplexing technique to the simultaneous sending of multiple CW signals. The suggested technique is in the category of the stepped-frequency GPR in that they are based on the frequency domain measurement. They have theoretically almost the same accuracy and SNR. But the scanning time of the suggested technique is incomparably fast than stepped-frequency GPR; hundreds of CW signals can be radiated at one time. To get the nice property, we need to pay additional signal processing process for it. In this paper, we handle the signal processing about impairments such as DC frequency, phase discontinuity, channel estimation, and frequency-edge non-linearity problem. Some simulation and experimental results are shown to address the impairments and performance of the suggested technique.