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A short-pulse K_a-band instrumentation radar for foliage attenuation measurements

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A portable K_a-band instrumentation radar for foliage attenuation measurements has been designed. It uses direct dielectric resonator oscillator multiplier pulse modulation giving a half power pulse width of 17 ns. The dual conversion scalar receiver utilizes either a digital storage oscilloscope in envelope detection format or a special gated comparator arrangement providing 1 m resolution and associated led seven segment display for data analysis. The calibrated dynamic range is better than 37 dB with an equivalent noise floor of 0.005 dBsm at 25 m test range distance. First experiments indicate an effective beamwidth close to 1°. The total weight is below 5 kg and the unit can be mounted on a conventional photographic tripod. Power is supplied from a 12 V/6 A h sealed lead acid battery giving an operating time in excess of 10 h. © *2008 American Institute of Physics.* [DOI: 10.1063/1.3006330]

Millimeter-wave radars have become attractive, for example, for vehicular collision avoidance purposes due to the reduction of component cost as seen during the past ten years or so. Most of the practical instruments seem to be allocated on the K_a- or V-bands, somewhere between 30 and 80 GHz. The relatively short wavelength enables the usage of reasonably sized antennas when observing desired distances of up to about 500 m.[1] Operation at sea or on long straight portions of roads and highways is relatively easy but one of the major drawbacks is the expectedly heavy attenuation caused by roadside vegetation and related obstacles when, for example, we are interested to detect a crossing vehicle hidden behind road-side bushes.

Foliage attenuation at millimeter-wave frequencies has been studied for military purposes since the 1960s at least in the former Soviet Union[2] but we were unable to find any recent references from there. In the United States particularly the Georgia Tech campaign that was started around 1970 on Department of Defense funding has been extensive in nature and has brought some attenuation data as well.[3] Typical attenuation values around 4 dB/m have been reported. Other partly European references[4] suggest the use of an empirical equation that gives one-way attenuation values of 3 dB/m to 12 dB/10 m but apparently this procedure is mainly intended for communication work. More research in this field has been carried out, for example, by the German automotive industry. Japanese sources[5] give 10 dB/m for the entire frequency range from 10 to 95 GHz, but a closer look at these papers reveals that they are based on original measurements by Trebits and Hayes in 1978 in the USA. A rather mystifying addition is given in Ref. 5 stating a seasonal variation of 10 dB, but no data are given about the thickness of the vegetation layer nor there is any indication of the type of foliage at hand.

Based on this very brief survey, we are already able to conclude that very little data are presently at hand for millimeter-wave attenuation estimation. Therefore a decision was made to conduct a short measurement campaign of our own and, for its purposes, a dedicated instrumentation radar suitable for true field operations had to be designed. This article describes the main characteristics of our first experimental setup.

Basically, it is possible to measure and record foliage attenuation with high-quality laboratory test equipment if one is ready to bring all that precious hardware out to the rather hostile environment. Real field tests, however, call for a dedicated system that is designed from the very beginning to withstand temperature variations (and extremes) and humidity, up to the point of short rain showers. Further on, because interesting sites tend to be hard to reach—even if the only obstacle is just one roadside ditch—the instrumentation shall be extremely portable and battery powered.

The more task-oriented technical requirements of the test instrumentation start with the dynamic range. Obviously two-way attenuation is measured by putting a known radar cross section (RCS) behind the foliage barrier and then by observing the resulting much reduced response. However, because temperature variations and possibly also changes in the relative humidity might alter our results, we should frequently check the nominal RCS of our test target as well. It is beneficial if we can record the unattenuated response with the same settings as the attenuated one and therefore we want to have a wide enough dynamic range. The second vital parameter is the ability to cancel the effect of foliage-based clutter from our results. This is achieved by keeping the illuminated area small, preferably close to the mechanical dimensions of our test target. This way clutter level is really low against the RCS of the target. Of course, we also have to obey the far field requirements in order to avoid clumsy conversions and manipulations later.

When we combine the effects of foliage-based surface clutter and simple two-way radar propagation, we can draw curves like the two shown in Fig. 1 illustrating the obtainable performance with different antennas when we assume a con-

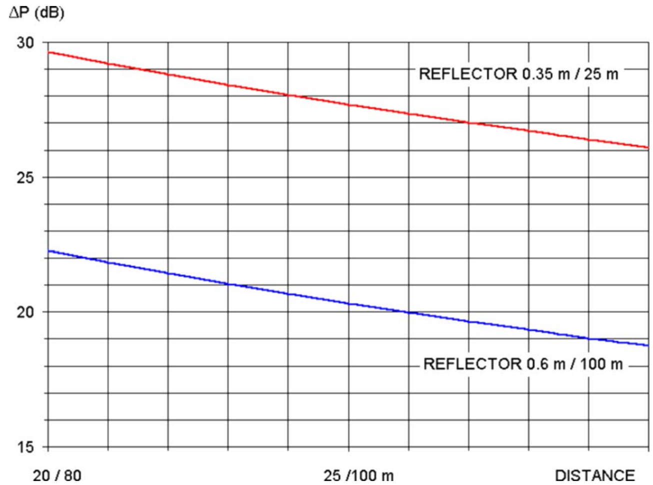

FIG. 1. (Color online) Available dynamic range with two different antennas against perpendicular surface clutter from foliage. Target RCS is 20 dBsm.

stant target RCS and an arbitrary but predefined radar transceiver. A small reflector-type antenna, in this case having a diameter of about 300 mm, not only gives a larger dynamic range against surface clutter but also makes practical arrangements a lot easier when our test range can be short. Naturally we have a lower overall instrument weight and size as well.

Although we can reduce the amount of surface clutter coming from foliage in front of the test target by having a narrow antenna beam, we must use very short pulses in order to limit the contribution possibly coming from forest or other targets located behind our reference. This means that as long as we do not compromise receiver noise performance, we have benefit of shortening the transmitted pulse. Here many commercially available test instruments would fail because we seldom see calibrated output amplitudes from millimeter-wave off-the-shelf generators for shorter than, say, 100 ns pulses. We concluded after some preliminary experiments that the construction shown schematically in Fig. 2 is suitable for the task. Our home-made transmitter is simply a dielectric resonator oscillator (DRO) oscillator followed by a varactor diode multiplier. The output pulse, whose half power width is just 17 ns, is formed by modulating the varactor bias with a longer 250 ns pulse. The coupling between the antenna, transmitter, and receiver is very simple with just one ferrite circulator. This is possible because we have deliberately limited the transmitter output power so as not to overload the first receiver stage. This gives a dramatic cost reduction and—which is even more important—allows us to have a very short dead zone in front of the radar. Typical high speed waveguide switches would require at least 200 ns to stabilize, thus throwing, the closest possible measuring distance much beyond 25 m. In the receiver we use first a balanced diode mixer having its local oscillator signal from a second DRO and an intermediate frequency (IF) amplifier chain where we also need one GaAs diode switch to prevent saturation in the following stages. No IF filtering is necessary and in fact would not have been of much help because of the huge uncompressed bandwidth of the output pulse. However, if the second, adjustable local oscillator is out of tune, some phantom power will be detected even when the pulses are not transmitted, which increases the noise level.

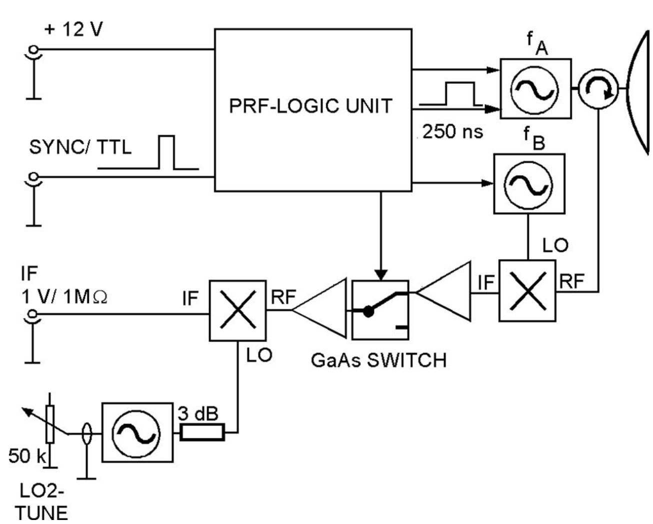

FIG. 2. A simplified schematic of the constructed instrument.

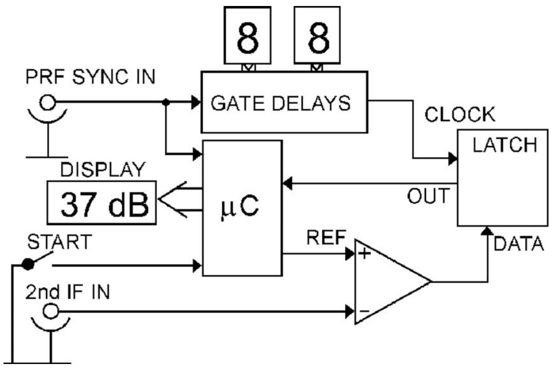

FIG. 3. Block diagram of the gated comparator level measuring system.

Besides the necessary very short transmitter pulses and an adequate receiver dynamic range, we have a third challenge to overcome—data acquisition. Normally radar people tend to use very high speed commercial data acquisition boards installed in office-type personal computers. In our case such an arrangement is clumsy, consumes far too much power, and produces huge amounts of digitized samples from useless noise. This is because in foliage attenuation measurements, we have a fixed-point target at a precisely known distance and in principle we need to know only one peak amplitude value of the return signal. Even if we want to know something of the temporal characteristics, the time constants are tens of milliseconds and more. Our solution is twofold. For system evaluation we selected a battery-powered digital oscilloscope that is capable of 1 Gsample/s for 50 000 display frame points. For extended field opera-

TABLE I. Key parameters of the radar.

Operating frequency	K_a-band (27–40 GHz)
Pulse repetition rate	1/120 s
Pulse length	18 ns (half power width)
Transmit power	10 dBm (peak)
Antenna size	300 mm
Effective beamwidth	~1°
Display	Oscilloscope or integrated RCS display
Power	12 V lead acid battery

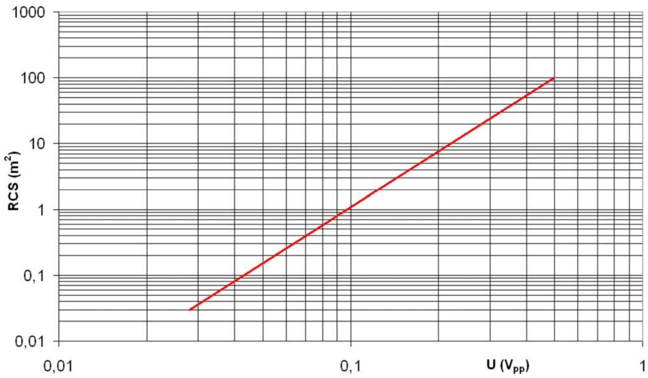

FIG. 4. (Color online) Measured response characteristics at 25 m distance.

tions we developed a range-gated system that records only one peak value for every pulse repetition interval.

The second IF at 50–150 MHz is the output that we use either for a digital storage oscilloscope's envelope display or for feeding a timed ultrafast comparator having a rise time below 7 ns. Gate delays, selected by rotary thumb wheel switches, are used to position the latch clock pulse edge at the desired distance with a resolution of 1 m. Initially we considered using a classical counter scheme for this delay process but discarded it due to the inconveniently high clock frequency (6.7 ns would require at least 150 MHz) and possible jitter problems. It turned out that high speed complementary metal-oxide-semiconductor logic gates from the 74HC series exhibit a very suitable nominal delay of 3–7 ns per gate and that this delay can be fine tuned by adjusting the integrated circuit supply voltage. If needed, temperature compensation can be added in this way as well. Already the breadboard prototype showed an uncertainty lower than about 20 cm for the entire least-significant digit range.

The calibrated RCS indicator that was designed for the radar consists of a LED display, a microcontroller, and a digital to analog converter (DAC). Display triggering happens with a separate push button. A reference voltage ramp is generated by the microcontroller and a high-quality 12 bit DAC. The voltage starts from a predefined maximum value, and it is incrementally decreased after certain number (8 in our case) of pulses has been transmitted.

The reference voltage is compared with the amplified and filtered detector signal and if the reference voltage is higher, the next lower voltage value is applied. When the correct signal level is found, the respective RCS value is searched from the table in the memory of the microcontroller and is shown on the display. Reference voltage is cycled down to the noise level, if signal is not detected earlier. A block diagram of the gated comparator level measuring system is illustrated in Fig. 3.

Due to variations in the operating temperature and radar equipment, RCS reading must be calibrated. In this system, display values are calculated with a personal computer software and the microcontroller is then reprogrammed, but in future versions the calibration routine will be included in the software of the microcontroller.

The whole instrument is built inside an IP65 class solid aluminum enclosure that also withstands pretty heavy shocks and static mechanical loads. A small removable box has been employed for local oscillator remote control (by wire). Because the whole device is handy in size, we can use an ordinary photography tripod as a pedestal. The present state of development allows the instrument to run for 10 h continuously from a single 12 V/6 A h sealed lead acid battery. Radar beam alignment is assisted by a sniper scope that has been collimated for desired test range distance. The most important parameters of the radar are collected in Table I.

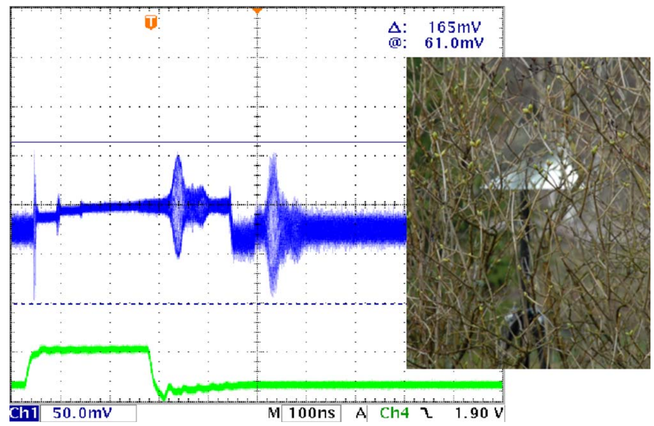

FIG. 5. (Color online) Recorded radar response from the target placed behind a road-side bush. The attenuation is 10–13 dB/m. The upper trace is the detected signal. The first pulse is the transmitted signal leaking through the circulator. Lower trace is the signal used to trigger the oscilloscope.

At the time of writing a comprehensive view of test results would be out of scope for this article. However, we want to show a typical example of obtainable results. RCS calibration was performed with several trihedral corner reflectors of different sizes and spherical targets. Figure 4 illustrates the calibrated response curve for 25 m test range distance. The smallest detectable RCS is about 0.005 m^2 assuming 0 dB signal-to-noise ratio. This was verified by a clear sky recording. We are thus well in line with the findings of Ref. 6 related to maximum foliage backscatter levels. While the measured noise floor—excluding clutter—is about 14 mV peak to peak, we can calculate the dynamic range, which exceeds 37 dB with this instrument. In Fig. 5 we see a case example: the reference target is placed behind the foliage (this time a typical subarctic road-side bush). The view in the photograph is from the radar location. The respective measured response is illustrated. The attenuation is 10–13 dB/m.

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