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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

98-153

TO: John Reed, FCC jreed@fcc.gov
FROM: Gary Olhoeft, PhD golhoeft@mines.edu

25 May 2001

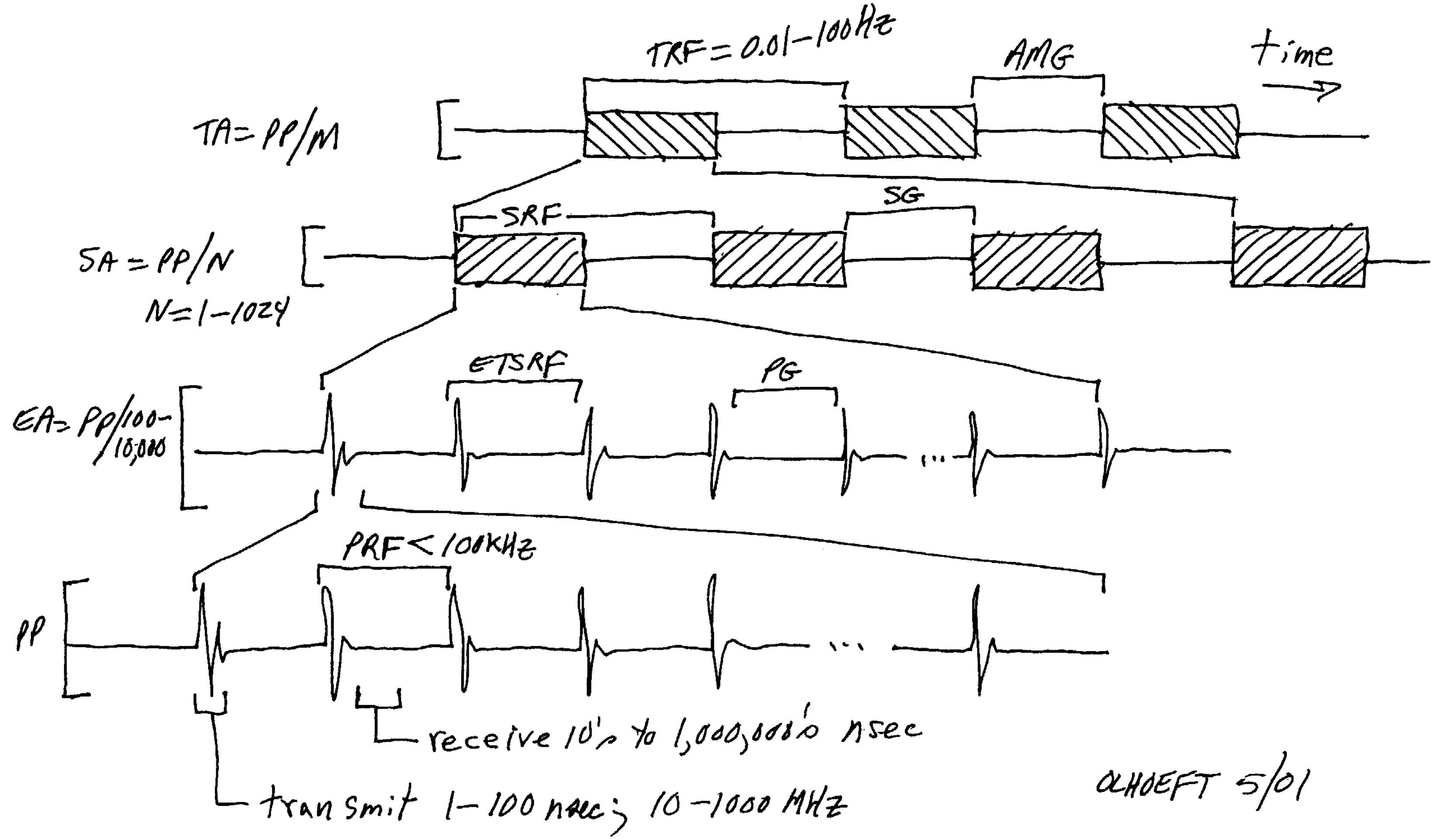
The attached figure illustrates the operation of a typical commercial impulse ground penetrating radar (FMCW, chirp and frequency domain systems are very different, but greater than 99% of commercial systems are impulse). From bottom to top: (all the numbers vary with manufacturer, antenna center frequency, application, logistical constraints, etc., but representative ranges are given, and the transmitter is off during all the "gaps" noted below)

I) The transmitter sends out a pulse from 1 to 100 nsec long (10 to 1000 MHz) at a pulse repetition frequency (PRF) typically less than 100 kHz (this is mostly limited by the speed of avalanche semiconductor recovery, A/D convertors, data transfer and disk storage rates, but lower frequency GPR's are also typically slower), and the receiver then listens for 10's to 10,000's of nsec (longer at lower frequencies to see deeper).
II) A large number (typically 500 to 1000) of these pulses are sent out so equivalent time sampling may be used to digitize and recover the high frequency data at rates of available, inexpensive A/D's and storage devices. Thus, the equivalent time sampled waveform repetition frequency (ETSRF))is the PRF/Z, where Z is the number of pulses used in the equivalent time waveform reconstruction (not counting any required processing gap, PG, for processing and storing the data, which is parallel with digitization on some systems). ETSRF is typically less than 100 Hz.
III) Depending upon ambient RF noise and depth requirements, sometimes these equivalent time sampled waveforms are added together ("stacked") to average and reduce random noise by sqrt(N) where N is the number of stacks, producing a stack repetition frequency (SRF) which is ETSRF/N (neglecting any required processing and storage gap, SG). Note that coherent noise, like from digitizers and computers will get worse by stacking.
IV) The radar system accumulates these sampled, digitized, and stacked waveforms ("traces" or "scans") at a rate controlled by the movement and positioning of the antenna for whatever geometry of measurement is required, with an antenna movement gap (AMG) during which the antenna is moved and the new location is determined (by a wheel, laser, GPS system, etc.) and stored, resulting in a trace repetition frequency (TRF) that can range from 0.01 Hz to 100 Hz, and be highly variable during a single data collection. (The high end of 100 Hz TRF is a continuously moving antenna with no stacking with 1000 digitized points per waveform and a 100 kHz PRF).

Thus, starting from the instantaneous, peak power of a single transmitted wavelet, the "time average" power can be lower by anything from a thousand to greater than a million times, depending upon over what interval you average and how many stacks are being used, rate of antenna movement, number of points per waveform, and pulse repetition frequency. Because time is money and because some hydrogeological processes are changing rapidly in time (a moving plume of pollutant for example), people usually try to setup for the fastest movement possible for the antenna. However, high stacks to reduce RF ambient noise, difficult position surveying, and tight logistical constraints all work to slow the data acquisition, so the peak to average power ratio rapidly approaches huge numbers (>10,000,000) when measured over intervals of seconds, but only 1,000 when measured over milliseconds. With improving digital technology, the ratio could conceivably drop to 100, but the several gaps can each multiply another factor of 2 or more to these numbers, and most digital improvements increase RF noise. Typical peak power numbers are a few watts. How would you like tro define "average" and over what interval?

One of the commercial GPR manufacturers has not had FCC waivers, but has several times had NTIA waivers when selling to federal agencies. Another has had their systems put through the same CE and FCC testing as computer systems, easily passing the Part 15 digital device rules above 100 MHz. However, below 100 MHz is a problem, because the antennas are bigger than the compliance testing laboratory facilities can handle, and they do not produce useful or meaningful numbers because they are ignoring variable ground loading, multpathing, near field (in "small" test rooms), polarization and deployment issues.

If you can tell us what you'd like to have in the way of numbers and specifications (the above requires an algorithm or nomogram approach), or even recommended test and certification procedures, I'll be happy to convene a small meeting (4 to 6 people) of users and manufacturers to draft a response for you that the geophysical community could live within. I think we've seen no complaints of interference in decades of GPR operation because the peak to "average" power ratio is a huge number in typical use, for typical victim receiver "averaging" and human response times (tens of milliseconds to seconds). For these reasons alone, I think it would be defensible to have an unlicensed, unintentional radiator, Part 15 exemption for geophysical subsurface investigation applications. In terms of interference, we do a LOT better than arc welders (and there are far fewer geophysical systems of all kinds)!


TRF = 0.01-100Hz
AMG
time
TA = PP/M
SRF
SG
SA = PP/N
N = 1-1024
ETSRF
PG
EA = PP/100-10,000
PRF < 100KHz
PP
receive 10's to 1,000,000's nsec
transmit 1-100 nsec; 10-1000 MHz
OLHOEFT 5/01

From: John Reed
To: "golhoeft@Mines.EDU".GWIA1.ROUTE_A; Karen Rackley
Date: 5/29/01 11:27AM
Subject: Re: peak to average power ratio

First, Bill would you please place a copy of this into the comment file for ET Docket 98-153 as a ex parte comment. I've attached the incoming discussion paper. Thanks.

Sorry I wasn't able to discuss this with you on Friday. I ended up being out of the office that day. Unfortunately, we don't know yet exactly what specifications will be implemented for ground penetrating radar (GPR) systems. This will not be determined until the Commission approves a Report and Order in this proceeding. In the interim, I can at least provide you with a brief run down of what has been addressed so far.

Under Section 15.209 of the Commission's regulations, average measurements are required for emissions above 1 GHz and between 9-90 kHz and 110-490 kHz. CISPR quasi-peak measurements are used between 90-110 kHz and 490 kHz - 1000 MHz. Measurements normally would be performed in accordance with the procedures contained in ANSI C63.4-1992, as specified in Section 15.31(a)(6). For emissions above 1 GHz, this requires the use of a 1 MHz resolution bandwidth (see Section 15.35(b)). The measurements are performed by the engineers at our Laboratory and I don't have a copy of ANSI C63.4, but if I recall correctly the video bandwidth for an average measurement would be about 1 kHz. However, you should note that the National Telecommunications and Information Administration (NTIA) under the Department of Commerce has insisted in its comments that we use an RMS reading for the average level. (NTIA is the agency that regulates US Government radio operations.) NTIA stated that RMS average could be measured using a spectrum analyzer with an RMS detector or that RMS could be computed from an amplitude probability distribution measurement. NTIA also indicated that we could measure the average level as we have in the past for narrow band pulsed emissions by multiplying the peak power in a bandwidth by the duty cycle, i.e., peak power = average power - 10 log (duty cycle).

NTIA provided a full discussion of its RMS measurement procedure in NTIA Report 01-383 and in NTIA Special Publication 01-43. Copies of these reports were placed in our electronic comment filing system for Docket No. 98-153 on January 18, 2001. (To make these easier to locate, they are in the filing group of comments number 120-140 as of this morning.)

In addition to the average limits, we proposed to limit the maximum peak signal within a 50 MHz bandwidth to no greater than 20 dB above the maximum permitted average level. This would result in a maximum peak limit of about -21.25 dBm/50 MHz EIRP. Some of the comments have asked for as much as 41 dB above the maximum average limit of 500 uV/m at 3 meters. We also proposed a limit on the total peak power generated by the device of no greater than 60 dB, depending on the total bandwidth of the device, above the maximum average limit of 500 uV/m at 3 meters. This would result in a total peak power limit of about 18.75 dBm EIRP. Several of the comments have argued that there is no need to specify a limit on total peak power while others have asked for power levels up to 1 kHz or so.

We recognize that, depending on the PRF, the UWB emissions would either be peak-limited or average-limited, i.e., one of the specifications, either peak or average, would be the controlling factor on the permitted output level. Also note that with a GPR these are not the emission levels directed from the antenna and conducted into the ground. Rather, they are the proposed limits for RF energy radiated from the device into the atmosphere. We proposed that GPRs include a switch or other mechanism to ensure that operation occurs only when the GPR is activated by an operator and the unit is aimed directly down at the ground. We also proposed to include within the definition that a GPR would be a UWB device that is designed to operate only when in contact with, or in close proximity (i.e., 1 meter) to, the ground. Our proposal to not measure the emissions directed from the antenna of a GPR did not encompass such devices as airborne GPRs.

With regard to the claim you've received from one GPR manufacturer that it has received several waivers from NTIA to sell to Government agencies, I discussed this issue with NTIA's staff and was told that no waivers have been issued. Besides, these waivers would have to be coordinated with the FCC. To date we have only had coordination for a couple of uses of a GPR by the Justice Department. The only waiver issued for a GPR is the one that was granted to US Radar. With regard to the company that has "had their systems put through the same CE and FCC systems as computer systems" please note that these systems are not computers but are intentional radiators and are required to be certified as transmitters. I also wonder how this test showed them to comply with the peak limit in Section 15.35(b) and (c) unless they failed to apply a pulse desensitization correction factor to the peak measurement. The current limit on total peak power above 1000 MHz is approximately -21.25 dBm EIRP.

The comment period for this proposal actually ended last October. However, we are continuing to evaluate the various filings. A late filing would still be evaluated if it is received soon. What we would be looking for is not just what the geophysical community "could live with," although that is of concern. What we actually need is the analysis as to the interference potential to the various authorized radio services. Within the frequency bands typically used by GPRs this would include several cricital safety services including: GPS systems within the band 1164-1610 MHz; search and rescue operations at 8.364 MHz, 123.1 MHz, 156.8 MHz, and 243 MHz; various aeronautical radionavigation bands; and several satellite earth receive station bands. You should note the previous interference studies submitted by NTIA and others on GPS and Government radar and aeronautical systems.

I hope this discussion helps clarify the standards we addressed. I would be happy to discuss this further if you desire.

John A. Reed
Senior Engineer
Technical Rules Branch

>>> "Gary R. Olhoeft" <golhoeft@Mines.EDU> 05/25/01 01:51PM >>>
Dear John,

The attached discussion should be of interest to your
peak to average power ratio question. It greatly depends
upon how you define "average" and over what interval...

Best regards,
-Gary

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CC: Franklin Wright; Fred Thomas; William Caton