NTIA Technical Memorandum 10-464

CORRECTION FACTORS AND MEASUREMENT PROCEDURE TO ASSESS THE INTERFERENCE IMPACT OF LINEAR SWEPT FREQUENCY SIGNALS ON RADIO RECEIVERS

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EXECUTIVE SUMMARY

The National Telecommunications and Information Administration (NTIA) is developing a handbook documenting the best practices in spectrum engineering. This technical memorandum provides a methodology to determine the average and peak power level at the output of a filter with a linear swept frequency pulse train input to the filter. Using this method, NTIA calculated two correction factors necessary to accurately compute the interference power level of a system that employs linear swept frequency signals. The two correction factors enable the conversion of the peak power at the filter input to the peak power or average power at the output. These correction factors cover the case where the peak input power is stated in dB relative to a reference power (e.g., dBW). NTIA also carried out, as part of this technical memorandum, measurements of linear swept frequency signals at the input and output of a variety of filter bandwidths. A comparison of measured and calculated correction factors showed the values to be in good agreement. The measurements carried out in this technical memorandum resulted in the development of a general procedure for measuring the emissions of a system employing linear swept frequency techniques. This method enables an accurate measurement of the emissions from which to assess compatibility with other radio services. The correction factors and the measurement procedure described in this technical memorandum will be used in the development of the Best Practices Handbook.

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GLOSSARY OF ACRONYMS AND ABBREVIATIONS

AWG	Arbitrary Waveform Generator
B_t	Extent of Frequency Sweep
BW	Bandwidth
BWCF	Bandwidth Correction Factor
BW_{3dB}	3 dB Filter Bandwidth
CF_A	Average Power Correction Factor
CF_P	Peak Power Correction Factor
EIRP	Equivalent Isotropically Radiated Power
IF	Intermediate Frequency
ITS	Institute for Telecommunication Sciences
kHz	Kilohertz
LNA	Low Noise Amplifier
MHz	Megahertz
msec	Millisecond
NTIA	National Telecommunications and Information Administration
OSM	Office of Spectrum Management
P_{AO}	Average Power at the Output of Filter
P_{Pi}	Peak Power at the Input of Filter
P_{PO}	Peak Power at the Output of Filter
PRT	Pulse Repetition Time
PW	Pulse Width
RBW	Resolution Bandwidth
RF	Radio Frequency
RMS	Root Mean Square
SR	Sweep Rate
τ_i	Input Pulse Width
UFS	Unit Under Test Frequency Sweep
UUT	Unit Under Test
µsec	Microsecond

SECTION 1.0
INTRODUCTION

1.1 BACKGROUND

The National Telecommunications and Information Administration (NTIA) Office of Spectrum Management is examining best practices in spectrum management for use by regulators, technology developers, manufacturers and service providers. This effort includes the development of a Best Practices Handbook that will aggregate a common set of approaches for conducting engineering analyses and will assemble a common set of criteria for performing technical studies to evaluate emerging technologies. NTIA will prepare a series of technical memorandums on various topics related to performing engineering analyses and will use the results of the individual technical memorandums to develop the Best Practices Handbook. This technical memorandum is one in a series addressing specific topics related to spectrum engineering.

An increasing number of federal and non-federal systems being developed employ linear swept frequency techniques. For compliance purposes the emissions from these devices are typically measured in a reference bandwidth (e.g., 1 MHz). To assess the compatibility of systems employing linear swept frequency techniques with other radio receivers, both average and peak power levels at the victim receiver intermediate frequency output are required. To perform this assessment, it is necessary to develop a means of converting the power (peak or average) of a linear swept frequency signal as measured in one bandwidth (e.g., reference bandwidth) to what would be expected in another bandwidth (victim receiver bandwidth). To perform this conversion, equations referred to as correction factors can be developed. In addition to providing a conversion for determining the peak or average power in different bandwidths, the correction factor can also be used to convert between peak and average power levels within the same bandwidth.

1.2 OBJECTIVE

The objective of the measurements and analyses described in this technical memorandum is to develop peak and average power correction factors for linear swept frequency signals. To accomplish this objective, NTIA conducted a series of tests providing measured data to support the understanding of the signal at the output of a filter over a range of filter bandwidths that results from each of a variety of input linear swept frequency signals. The measurements carried out in this technical memorandum will be used to develop a general procedure for measuring the emissions of a system employing linear swept frequency techniques.

1.3 APPROACH

The NTIA Institute for Telecommunication Sciences (ITS), in conjunction with the NTIA Office of Spectrum Management, performed the measurements described in this technical memorandum.

During the initial phase of the program, NTIA developed a linear swept frequency signal source. The swept frequency signal source was capable of generating a constant amplitude signal that swept across a range of at least 15 MHz with sweep rates of 0.005, 0.05, 0.5, 5, 50 and 500 kHz per microsecond (μsec). The carrier frequency was not a critical parameter in this measurement program.

The swept frequency signals were input to a spectrum analyzer. With the spectrum analyzer in a zero span mode at a frequency that is at the mid-point of the 15 MHz sweep range of the swept frequency signal generator, signals were measured in the spectrum analyzer with resolution bandwidths (RBWs) of 3 MHz, 1MHz, 300 kHz, 100 kHz, 30 kHz, and 10 kHz for each of the sweep rates.

The signal was measured using the root-mean-square (RMS) average and peak detectors. The peak and average power levels were measured using the maximum hold feature of the spectrum analyzer for approximately ten scans of the source signal. These multiple scans were performed for each of the sweep rates. The average power using the RMS average detector was measured over a 1 millisecond (msec) time interval. The peak power for each input signal was obtained.

In addition, similar spectrum analyzer measurements of peak and average power were carried out with the swept frequency held constant at 500 kHz/μsec and the pulse repetition time varied (600 μsec, 1.1 msec, and 6 msec). These additional measurements show the impact of duty cycle on the average power.

NTIA then analyzed the measured data along with certain analytical representations to develop a methodology to convert the peak power at a filter input to the peak or average power at the filter output.

SECTION 2.0
ANALYTICAL APPROACH

2.1 INTRODUCTION

This section presents the development of the analytical expressions to determine the peak and average power correction factors for linear swept frequency signals. The correction factors are used to determine the peak and average power expected at the output of a filter with a linear swept frequency pulse train at the filter input.

2.2 PEAK POWER CORRECTION FACTOR

The input pulse train considered in this analysis is characterized by the following parameters:

- P_{Pi} is the peak power of a rectangular pulse at the filter input (Watts);
- τ_t is the pulse width of the rectangular pulse (μsec);
- B_t is the extent of the linear frequency sweep during the pulse on-time (τ_t) (MHz); and
- PRT is the pulse repetition time, the time from the start of one pulse to the start of the next pulse (μsec).

The sweep rate (SR) of the pulse (with units of MHz/μsec) is determined by:

$$SR = B_t/\tau_t \qquad (2\text{-}1)$$

The filter is characterized by its 3 dB bandwidth (B_{3dB}) in MHz. For the analysis presented in this technical memorandum to be applicable, B_t must be greater than B_{3dB}. If B_t is less than B_{3dB}, the total frequency sweep falls within the filter bandwidth and is not addressed in this technical memorandum.

The reduction in peak power, as the input pulse passes through the filter, is determined by the ratio of the time the swept frequency signal is within the filter bandwidth (i.e., B_{3dB}/SR) to the response time of the filter. The response time of the filter is $1/B_{3dB}$. Thus, the peak power at the output of the filter (P_{Po} in Watts) is:

$$P_{Po} = P_{Pi}\,[(B_{3dB}/SR)/(1/\,B_{3dB})] = P_{Pi}\,[(B_{3dB})^2/SR] \qquad (2\text{-}2)$$

This result can be expressed as a peak correction factor (CF_P) in dB, which provides a method to correct the peak power of the input pulse to account for the filter bandwidth effect. Expressing Equation 2-2 in logarithmic form results in:

$$10\ \mathrm{Log}\,(P_{Po}) = 10\ \mathrm{Log}(P_{Pi}) + 10\ \mathrm{Log}\,[(B_{3dB})^2/SR] \qquad (2\text{-}3)$$

The term $10\ \mathrm{Log}\,[(B_{3dB})^2/SR]$ is CF_P. If the peak power at the input is expressed in units of dB relative to a reference power (in dBW), the CF_P can be applied to determine the output in the same power units. There is, however, a limit on the range of applicability of $CF_P = 10 \text{ Log} [(B_{3dB})^2/SR]$. The peak correction factor cannot exceed 0 dB or $(B_{3dB})^2/SR$ cannot exceed one. That is, if $(B_{3dB})^2/SR$ is greater than one, it should be set equal to one to determine CF_P. If CF_P where allowed to have a value greater than 0 dB, the peak power out of the filter would be greater than the peak power into the filter, which is not possible.

2.3 AVERAGE POWER CORRECTION FACTOR

Once the peak power at the output of the filter has been determined, the average power at the output (P_{Ao} in Watts) of the filter can be determined by taking into account the duty cycle of the output pulse train:

$$P_{Ao} = P_{Po} (\tau_o/PRT) \quad (2\text{-}4)$$

where τ_o is the pulse length at the filter output. This is also the response time of the filter:

$$\tau_o = 1/B_{3dB} \quad (2\text{-}5)$$

Combining Equations 2-2 and 2-4 results in:

$$P_{Ao} = P_{Pi} [(B_{3dB})^2/SR] [1/(B_{3dB} \text{ x } PRT)] = P_{Pi} [B_{3dB}/(SR \text{ x } PRT)] \quad (2\text{-}6)$$

This produces a correction factor (in logarithmic form) for average power (CF_A) in the same units as that of the peak power (e.g., dBW or dBm):

$$CF_A = 10 \text{ Log} [B_{3dB}/(SR \text{ x } PRT)] \quad (2\text{-}7)$$

SECTION 3.0
ANALYSIS OF MEASUREMENTS

3.1 DESCRIPTION OF MEASUREMENTS

In order to confirm the analytical results presented in Section 2, NTIA ITS performed a series of measurements. The measurements initially involved configuring a signal generator to linearly sweep from 92.5 to 107.5 MHz. The linearity of the sweep was confirmed using a vector signal analyzer. The slowest sweep rate used was 5 Hz/μsec and the fastest was 500 kHz/μsec. NTIA ITS used a spectrum analyzer to measure the peak and average power at the output of the RBW filter. These RBW filters are incorporated in the spectrum analyzer and have a Gaussian selectivity characteristic. The average power measurements were made using a RMS detector with an integration time of 1 msec for the initial measurements.

The pulse-on time of the pulse train was established by the sweep rate selected for the specific measurement and the extent of the frequency sweep (92.5 to 107.5 MHz). The off-time between pulses was very short initially such that the difference between total peak and average power at the filter input was less than 3 dB. The spectrum analyzer was operated in the zero-span mode with maximum hold and tuned to the center frequency of the frequency sweep of the pulse.

3.2 DISCUSSION OF MEASUREMENTS

3.2.1 Peak Power Measurements

Table 3-1 provides a summary of the peak power measurement results. As shown in Table 3-1, the measured peak power at the output of the RBW filter relative to the input of the filter is a function of the bandwidth and sweep rate. The quantity measured is the difference between maximum peak power at the filter input and the measured peak power at the filter output for a combination of sweep rate and filter bandwidths, $CF_P = 10 \text{ Log } [(B_{3dB})^2/SR]$.

Table 3-2 shows a comparison of measured and calculated CF_P values. As shown in Table 3-2, the calculated CF_P values are higher in magnitude than the measured CF_P values. This indicates that the analytical expression developed in Section 2 provides an overestimate of the actual CF_P. Thus, it is necessary to modify the equation for CF_P developed in Section 2. Including a factor of 1.6 in Equation 2-3 results in CF_P values in better agreement with the measurements as shown in the last column in Table 3-2.

Table 3-1. Measured Peak Power Correction Factors for Various Sweep Rates

Sweep Rate (kHz/μsec)	RBW	Measured CF_P (dB)
$5x10^{-3}$	3 MHz	0
$5x10^{-2}$	3 MHz	0
$5x10^{-1}$	3 MHz	0
5	3 MHz	0
$5x10^{1}$	3 MHz	0
$5x10^{2}$	3 MHz	0
$5x10^{-3}$	1 MHz	0
$5x10^{-2}$	1 MHz	0
$5x10^{-1}$	1 MHz	0
5	1 MHz	0
$5x10^{1}$	1 MHz	0
$5x10^{2}$	1 MHz	0
$5x10^{-3}$	300 kHz	0
$5x10^{-2}$	300 kHz	0
$5x10^{-1}$	300 kHz	0
5	300 kHz	0
$5x10^{1}$	300 kHz	-1
$5x10^{2}$	300 kHz	-5
$5x10^{-3}$	100 kHz	0
$5x10^{-2}$	100 kHz	0
$5x10^{-1}$	100 kHz	0
5	100 kHz	0
$5x10^{1}$	100 kHz	-5
$5x10^{2}$	100 kHz	-15
$5x10^{-3}$	30 kHz	0
$5x10^{-2}$	30 kHz	0
$5x10^{-1}$	30 kHz	0
5	30 kHz	-5
$5x10^{1}$	30 kHz	-15
$5x10^{2}$	30 kHz	-25
$5x10^{-3}$	10 kHz	0
$5x10^{-2}$	10 kHz	0
$5x10^{-1}$	10 kHz	-4
5	10 kHz	-15
$5x10^{1}$	10 kHz	-24
$5x10^{2}$	10 kHz	-32

Table 3-2. Comparison of Measured and Calculated Peak Power Correction Factors for Various Sweep Rates

Sweep Rate (kHz/μsec)	RBW	Measured CF_P (dB)	Calculated CF_P $10 \text{ Log } [(B_{3dB})^2/SR]$ (dB)	Calculated CF_P $10 \text{ Log } 1.6 [(B_{3dB})^2/SR]$ (dB)
$5x10^{-3}$	3 MHz	0	0	0
$5x10^{-2}$	3 MHz	0	0	0
$5x10^{-1}$	3 MHz	0	0	0
5	3 MHz	0	0	0
$5x10^{1}$	3 MHz	0	0	0
$5x10^{2}$	3 MHz	0	0	0
$5x10^{-3}$	1 MHz	0	0	0
$5x10^{-2}$	1 MHz	0	0	0
$5x10^{-1}$	1 MHz	0	0	0
5	1 MHz	0	0	0
$5x10^{1}$	1 MHz	0	0	0
$5x10^{2}$	1 MHz	0	0	0
$5x10^{-3}$	300 kHz	0	0	0
$5x10^{-2}$	300 kHz	0	0	0
$5x10^{-1}$	300 kHz	0	0	0
5	300 kHz	0	0	0
$5x10^{1}$	300 kHz	-1	0	0
$5x10^{2}$	300 kHz	-5	-7.4	-5.4
$5x10^{-3}$	100 kHz	0	0	0
$5x10^{-2}$	100 kHz	0	0	0
$5x10^{-1}$	100 kHz	0	0	0
5	100 kHz	0	0	0
$5x10^{1}$	100 kHz	-5	-7	-4.9
$5x10^{2}$	100 kHz	-15	-17	-14.9
$5x10^{-3}$	30 kHz	0	0	0
$5x10^{-2}$	30 kHz	0	0	0
$5x10^{-1}$	30 kHz	0	0	0
5	30 kHz	-5	-7.4	-5.4
$5x10^{1}$	30 kHz	-15	-17	-15.4
$5x10^{2}$	30 kHz	-25	-27	-25.4
$5x10^{-3}$	10 kHz	0	0	0
$5x10^{-2}$	10 kHz	0	0	0
$5x10^{-1}$	10 kHz	-4	-7	-4.9
5	10 kHz	-15	-17	-14.9
$5x10^{1}$	10 kHz	-24	-27	-24.9
$5x10^{2}$	10 kHz	-32	-37	-34.9

NTIA ITS carried out additional peak power measurements with the sweep rate held constant at 500 kHz/µsec and the PRT varied (600 µsec, 1.1 msec, and 6 msec). The data set previously discussed included data for a sweep rate of 500 kHz/ µsec and a PRT of 60 µsec. Table 3-3 shows these data sets and peak power correction factors. As shown in Table 3-3, the peak power correction is not dependent on the PRT.

Table 3-3. Comparison of Measured and Calculated Peak Power Correction Factors (Sweep Rate of 500 kHz/600 µsec)

Spectrum Analyzer RBW	PRT	Measured CF_P (dB)	Calculated CF_P $10 \text{ Log } [(B_{3dB})^2/SR]$ (dB)	Calculated CF_P $10 \text{ Log } 1.6 [(B_{3dB})^2/SR]$ (dB)
3 MHz	60 µsec	0	0	0
3 MHz	600 µsec	0	0	0
3 MHz	1.1 msec	1	0	0
3 MHz	6 msec	1	0	0
1 MHz	60 µsec	0	0	0
1 MHz	600 µsec	0	0	0
1 MHz	1.1 msec	0	0	0
1 MHz	6 msec	0	0	0
300 kHz	60 µsec	-5	-7.4	-5.4
300 kHz	600 µsec	-5	-7.4	-5.4
300 kHz	1.1 msec	-5	-7.4	-5.4
300 kHz	6 msec	-5	-7.4	-5.4
100 kHz	60 µsec	-15	-17	-14.9
100 kHz	600 µsec	-14	-17	-14.9
100 kHz	1.1 msec	-14	-17	-14.9
100 kHz	6 msec	-14	-17	-14.9
30 kHz	60 µsec	-25	-27.4	-25.4
30 kHz	600 µsec	-25	-27.4	-25.4
30 kHz	1.1 msec	-24	-27.4	-25.4
30 kHz	6 msec	-24	-27.4	-25.4
10 kHz	60 µsec	-32	-37	-34.9
10 kHz	600 µsec	-34	-37	-34.9
10 kHz	1.1 msec	-34	-37	-34.9
10 kHz	6 msec	-34	-37	-34.9

3.2.2 Average Power Measurements

Table 3-4 provides a summary of the average power measurement results. The table shows that the measured average power at the output of the RBW filter relative to the peak power at the filter input as a function of RBW and sweep rate. The quantity of interest is $CF_A = 10 \text{ Log } [B_{3dB}/(SR \times PRT)]$, which is the difference between the peak power at the input of the filter and the average power at the output. However, this formula for CF_A assumes the integration time for the average power measurement is long enough to include at least one full pulse repetition period at the filter output. If a full pulse repetition period is not included in the integration time, a true average power measurement for the pulse train cannot be obtained. For most linear swept frequency signals, the integration time will be sufficient. However, for some of the measurements presented here this was not true and for those cases the formulation $CF_A = 10 \text{ Log } [B_{3dB}/(SR \times PRT)]$ is not applicable. This does not mean the average power cannot be calculated for these special cases, but a slightly different approach must be employed. The first such case occurs when the integration time (1 msec for these measurements) is less than the time the swept frequency signal is within the RBW. The time the swept frequency signal is within the RBW is B_{3dB}/SR. For this case, the pulse is present for the full integration time and there is no interpulse period in the integration time. The output will be equal to peak power at the input. This results in $CF_A = 0$ dB. These cases are denoted by a single asterisk accompanying the CF_A entry in Table 3-4. The second case occurs when the swept frequency signal spends less time in the filter than the integration time, but the PRT is longer than the integration time. For this case, the average power is measured for a condition where only a portion of the interpulse period is considered in the averaging. The correction factor is calculated by the ratio of the time the signal falls within the filter to the integration time, $CF_A = 10 \text{ Log } [(B_{3dB}/SR)/1x10^3]$. These cases are denoted by a double asterisk accompanying the CF_A entry in Table 3-4. For the third case, the formulation $CF_A = 10 \text{ Log } [B_{3dB}/(SR \times PRT)]$ applies. These complications requiring special consideration can be overcome by the judicious selection of the integration time for the specific signal and filter bandwidth being measured. The measurements that are the subject of this technical memorandum includes a range of sweep rates that covered five orders of magnitude and filter RBWs that covered two orders of magnitude. This wide range of parameters made it difficult to select an integration time. The determination of CF_A requires values of PRT. Table 3-5 contains these PRT values for each value of SR that was analyzed in Table 3-4.

Additional average power measurements were carried out with the sweep rate held constant at 500 kHz/µsec and the PRT varied (600 µsec, 1.1 msec and 6 msec). The data set that was discussed previously included data for a sweep rate of 500 kHz/sec and a PRT of 60 µsec. Table 3-6 provides these data sets and the average power correction factors. The Table 3-6 data was for an integration time of 1 msec. These additional measurements were performed to examine some of the Case 1 and Case 2 data in Table 3-4. This did not eliminate all of the "special" cases. As shown in Table 3-6, there are some Case 2 conditions where the integration time for the determination of overall average power was too short. Measurements were then performed for the twelve Case 2 entries in Table 3-6 with an integration time of 30 msec. This integration time exceeds the longest PRT of 6 msec and thus the overall average should be realized. The results of these measurements and calculations are shown in Table 3-7.

Table 3-4. Comparison of Measured and Calculated Average Power Correction Factors for Various Sweep Rates

Sweep Rate (kHz/μsec)	RBW	Measured CF_A (dB)	Calculated CF_A (dB)
$5x10^{-3}$	3 MHz	0	0^{*}
$5x10^{-2}$	3 MHz	0	0^{*}
$5x10^{-1}$	3 MHz	0	0^{*}
5	3 MHz	-3	-2.2^{**}
$5x10^{1}$	3 MHz	-9	-10^{***}
$5x10^{2}$	3 MHz	-10	-10^{***}
$5x10^{-3}$	1 MHz	0	0^{*}
$5x10^{-2}$	1 MHz	0	0^{*}
$5x10^{-1}$	1 MHz	0	0^{*}
5	1 MHz	-7	-7^{**}
$5x10^{1}$	1 MHz	-14	-14.8^{***}
$5x10^{2}$	1 MHz	-15	-14.8^{***}
$5x10^{-3}$	300 kHz	0	0^{*}
$5x10^{-2}$	300 kHz	0	0^{*}
$5x10^{-1}$	300 kHz	-2	-2.2^{**}
5	300 kHz	-12	-12^{**}
$5x10^{1}$	300 kHz	-19	-20^{***}
$5x10^{2}$	300 kHz	-20	-20^{***}
$5x10^{-3}$	100 kHz	0	0^{*}
$5x10^{-2}$	100 kHz	0	0^{*}
$5x10^{-1}$	100 kHz	-6	-7^{**}
5	100 kHz	-17	-17^{**}
$5x10^{1}$	100 kHz	-24	-24.8^{***}
$5x10^{2}$	100 kHz	-24	-24.8^{***}
$5x10^{-3}$	30 kHz	0	0^{*}
$5x10^{-2}$	30 kHz	-3	-2.2^{**}
$5x10^{-1}$	30 kHz	-12	-12.2^{**}
5	30 kHz	-22	-22.2^{**}
$5x10^{1}$	30 kHz	-29	-30^{***}
$5x10^{2}$	30 kHz	-29	-30^{***}
$5x10^{-3}$	10 kHz	0	0^{*}
$5x10^{-2}$	10 kHz	-6	-7^{**}
$5x10^{-1}$	10 kHz	-16	-17^{**}
5	10 kHz	-27	-27^{**}
$5x10^{1}$	10 kHz	-33	-34.7^{***}
$5x10^{2}$	10 kHz	-32	-34.7^{***}

* Case 1 – Time in filter longer than integration time: CF_A = 0 dB
**Case 2 – PRT longer than integration time: CF_A = 10 Log (Time in Filter/Integration Time)
***Case 3 – PRT less than integration time: CF_A = 10 Log [B_{3dB}/(SRxPRT)]

Table 3-5. Summary of Sweep Rates and Pulse Repetition Times

SR (kHz/µsec)	PRT (µsec)
$5x10^{-3}$	$2.97x10^{6}$
$5x10^{-2}$	$319x10^{3}$
$5x10^{-1}$	$50.6x10^{3}$
5	$6x10^{6}$
$5x10^{1}$	600
$5x10^{2}$	60

Table 3-6. Comparison of Measured and Calculated Average Power Correction Factors (Sweep Rate of 500 kHz/µsec)[1]

Spectrum Analyzer RBW	PRT	Measured CF_A (dB)	Calculated CF_A 10 Log [B_{3dB}/(SR x PRT)] (dB)
3 MHz	60 µsec	-10	-10
3 MHz	600 µsec	-19	-20
3 MHz	1.1 msec	-22	-22.2*
3 MHz	6 msec	-22	-22.2*
1 MHz	60 µsec	-15	-14.8
1 MHz	600 µsec	-23	-24.8
1 MHz	1.1 msec	-26	-27*
1 MHz	6 msec	-26	-27*
300 kHz	60 µsec	-20	-20
300 kHz	600 µsec	-29	-30
300 kHz	1.1 msec	-32	-32.2*
300 kHz	6 msec	-32	-32.2*
100 kHz	60 µsec	-24	-24.8
100 kHz	600 µsec	-33	-34.8
100 kHz	1.1 msec	-36	-37*
100 kHz	6 msec	-36	-37*
30 kHz	60 µsec	-29	-30
30 kHz	600 µsec	-39	-40
30 kHz	1.1 msec	-42	-42.2*
30 kHz	6 msec	-42	-42.2*
10 kHz	60 µsec	-32	-34.8
10 kHz	600 µsec	-43	-44.8
10 kHz	1.1 msec	-46	-47*
10 kHz	6 msec	-46	-47*
* Case 2 – PRT longer than integration time: CF_A = 10 Log(Time in Filter/Integration Time)			

1. An integration time of 1 msec was used to determine the RMS.

Table 3-7. Comparison of Measured and Calculated Average Power Correction Factors (Sweep Rate of 500 kHz/μsec)[2]

Spectrum Analyzer RBW	PRT	Measured CF_A (dB)	Calculated CF_A 10 Log $[B_{3dB}/(SR \times PRT)]$ (dB)
3 MHz	1.1 msec	-22	-22.6
3 MHz	6 msec	-29	-30
1 MHz	1.1 msec	-27	-27.4
1 MHz	6 msec	-33	-34.7
300 kHz	1.1 msec	-32	-32.6
300 kHz	6 msec	-39	-40
100 kHz	1.1 msec	-37	-37.4
100 kHz	6 msec	-43	-44.7
30 kHz	1.1 msec	-42	-42.6
30 kHz	6 msec	-49	-50
10 kHz	1.1 msec	-47	-47.4
10 kHz	6 msec	-54	-54.7

3.2.3 Applications of Linear Swept Frequency Correction Factors

For many applications of the linear swept frequency analysis, the peak and/or average power will be referenced in a specific bandwidth (e.g., Y dBm/MHz). The CF equations, $CF_P = 10 \text{ Log } 1.6[(B_{3dB})^2/SR]$ and $CF_A = 10 \text{ Log } [B_{3dB}/(SR \times PRT)]$, show that CF_P varies as 20 Log (B_{3dB}) and CF_A varies as 10 Log (B_{3dB}). This lends itself to the concept of a bandwidth correction factor (BWCF). Thus, where an average power level referenced to a certain bandwidth (B_1) needs to be converted to another bandwidth (B_2), the factor 10 Log(B_2/B_1) must be added to the reference power to determine the average power in B_2. Similarly, to convert the peak power in a reference bandwidth (B_1) to that in a bandwidth (B_2), 20 Log (B_2/B_1) must be added to the reference power level. It is also possible to convert the peak power in a given bandwidth (B_1) to the average power in the same bandwidth by adding -10 Log $(1.6 \times B_1 \times PRT)$ to the peak power. Similarly, the average power in a given bandwidth can be converted to the peak power in the same bandwidth by adding 10 Log $(1.6 \times B_1 \times PRT)$ to the average power.

All these bandwidth corrections are subject to the limitation that the peak correction factor $CF_P = 10 \text{ Log } [1.6 \times (B_{3dB})^2/SR]$ cannot exceed 0 dB. If the correction factor exceeds 0 dB, CF_P should be set equal to 0 dB.

2. An integration time of 30 msec was used to determine the RMS.

SECTION 4.0
GENERAL MEASUREMENT PROCEDURE FOR LINEAR SWEPT FREQUENCY SIGNALS

4.1 GENERAL MEASUREMENT PROCEDURE

The Federal Communications Commission Part 15 Rules permit devices that employ swept frequency techniques. The Commission's Rules require that the compliance measurements for swept frequency devices be performed with the frequency sweeping turned off.[3] Performing the compliance measurements with the frequency sweeping stopped ensures that the maximum emission levels generated by the device are captured. However, performing the compliance measurements with the frequency sweeping turned off may tend to overestimate the emissions generated by the device. Performing the compliance measurements with the frequency sweeping active could provide a more accurate representation of the emissions generated by the device while in its operational mode. Also, measuring emissions with the frequency sweeping turned off would require a special test mode be added to the device. Altering the device strictly for this purpose could produce measurement results that may not accurately represent the emissions generated while the device is operating as intended. The challenge is to develop a general compliance measurement procedure that is applicable to the different implementations of a swept frequency system (e.g., sweep rates, sweep frequency ranges). The measurement procedure would also have to provide an accurate measurement of the emissions so that they can be used to assess compatibility with other radio services. This section provides a description of a general measurement procedure for measuring the emissions of a linear swept frequency system with the frequency sweeping active.

4.2 DESCRIPTION OF GENERAL MEASUREMENT PROCEDURE

The measurement techniques employed in this technical memorandum can be used to develop a general procedure for measuring the emissions of systems employing linear swept frequency signals. These measurements are applicable to linear swept frequency systems where the extent of the frequency sweep is at least 3 MHz. All the measurements will be made with the unit-under-test (UUT) operating in the swept frequency mode.

The measurement approach requires the measurement of radiated measurements and should be carried out in a shielded enclosure. If a shielded enclosure is not available, a test site should be selected where the background radio-frequency (RF) environment is fairly quiet in the range of frequencies of concern. This background RF environment should be monitored periodically through the test period and this data must be included in the test report.

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3. 47 C.F.R. Section 15.31(c).

The required test equipment includes a spectrum analyzer with a peak and root-mean-square detector and maximum hold capability, a reference measurement antenna (for the frequency range of interest), a wide-band detector, an oscilloscope, and suitable cables to connect the test equipment. A low-noise amplifier (LNA) should be used to maximize the dynamic range of the measurement system. The LNA should be connected directly to the output of the measurement antenna. In addition, a separate variable frequency generator (or suitable substitute) is required to calibrate the measurement system.

The test description reported here is based on a UUT antenna that is not an extensive array. An extensive array would have at least one dimension greater than one-third the distance separation from the UUT antenna to the reference measurement antenna. If the array is extensive, the test procedure would need to be repeated for various measurement antenna placements that result in a meaningful sample of the emissions from the UUT.

The reference measurement antenna is to be positioned at a level and orientation to be within the mainbeam of the UUT antenna. The reference antenna is to be separated from the UUT antenna by a minimum distance for far-field antenna conditions and close enough so that the received signal is strong enough to carry-out the required measurements. However, the final measurements will need appropriate adjustments to determine UUT equivalent isotropically-radiated-power (EIRP) values.

The first series of measurements requires the spectrum analyzer to be connected to the measurement antenna through appropriate cables and the LNA, if required. The spectrum analyzer is to be operated in the frequency sweep mode with the frequency span of the spectrum analyzer frequency sweep set to be slightly greater than the UUT frequency sweep. With the spectrum analyzer in the maximum hold mode and using the peak detector, the UUT signal is to be measured over many scans until the individual peak power values no longer increase with each scan. Measurements are made for resolution bandwidths of 1 and 3 MHz. These measurements will show the extent of the UUT frequency sweep (UFS).

The second series of tests requires the wide-band detector and oscilloscope to be placed in the test setup as a substitute for the spectrum analyzer. The time waveform of the UUT pulse train is to be measured to determine the pulse width (PW) and pulse repetition time (PRT) of the UUT signal.

The third series of measurements requires the spectrum analyzer to be placed in the test setup as a substitute for the detector/oscilloscope and operated in the zero span mode with maximum hold. These zero span measurements should be performed at frequencies corresponding to 10 percent, 50 percent, and 90 percent of the UUT frequency sweep. The time per division setting of the spectrum analyzer should be such that many frequency sweeps of the UUT are measured in one sweep of the spectrum analyzer and a line is traced across the spectrum analyzer display. At the 10 percent frequency with the peak detector selected, the peak power is to be measured for resolution bandwidths of 3 MHz, 1 MHz, 300 kHz, and 100 kHz. The spectrum analyzer should then be tuned to the

50 percent frequency and the above measurements repeated. The spectrum analyzer should then be tuned to the 90 percent frequency and the measurements repeated. Then the RMS detector should be selected and the average power measured for each of the conditions established above in this paragraph. The integration time for the average power measurements should be at least 5 to 10 times the PRT. The distance between the UUT antenna and the reference measurement antenna should be measured and recorded. The gain of the measurement antenna, preferably across the frequency range of the UUT swept frequency, but at least at the 10 percent, 50 percent, and 90 percent test frequencies, should be determined from manufacturer specifications or from antenna gain measurements. The gain (loss) from the measurement antenna output through the spectrum analyzer must be measured, preferably across the frequency range of the UUT swept frequency, but at least at the 10 percent, 50 percent, and 90 percent test frequencies. This can be determined by connecting the variable frequency generator to the cable or LNA that was connected to the test antenna output with the generator set to a known peak power output level and then sweeping the generator across the frequency range of interest while measuring peak power at the spectrum. The difference between power in and power out expressed in decibel is the required calibration factor.

The average EIRP in a 1 MHz bandwidth can be determined by adjusting the average power levels (measured in the third series of tests in a 1 MHz bandwidth) to account for propagation path loss at the measurement distance, measurement antenna gain, and the gain (loss) measured for the cables and the LNA used in the measurement system. The average EIRP is to be determined at each of the test frequencies used in the third series of tests.

The peak EIRP must be determined for the bandwidth stipulated in the certification requirements. For example, the certification might stipulate the peak EIRP in a 50 MHz bandwidth or the total peak EIRP. For the peak EIRP determination, the peak power measured in 3 MHz (from the third series of tests) will be the basis. The measured peak power must be adjusted for propagation loss, measurement antenna gain, and the cable/LNA gain (loss). This yields the EIRP in a 3 MHz bandwidth. To determine the peak EIRP in any bandwidth, a limiting bandwidth (B) must be determined,

$$B = \sqrt{UFS/(1.6PW)} \tag{4-1}$$

where:

UFS is the extent of the UUT frequency sweep (MHz); and
PW is the UUT pulse width (microseconds).

At this limiting bandwidth, the total peak power will be realized at the filter output and thus increasing the bandwidth beyond B will not increase the peak power observed. If the certification stipulates a bandwidth less than B, then the EIRP in 3 MHz is increased in decibel by 20 Log (reference bandwidth (MHz)/3). If the reference bandwidth is greater than or equal to B or if the total power peak EIRP is needed in a 3 MHz bandwidth, then the EIRP in 3 MHz is increased in dB by 20 Log (B/3).

SECTION 5.0
CONCLUSIONS

5.1 CONCLUSIONS

This technical memorandum develops a methodology to determine the average and peak power level at the output of a filter with a linear swept frequency pulse train input to the filter. The correction factors are necessary to accurately compute the interference power level of a system that employs linear swept frequency signals. Two correction factor equations were developed to correct the peak power at the filter input to the peak power or average power at the output. These correction factors are used for the case where the peak input power is stated in dB relative to a reference power (e.g., dBW). The correction factor to yield the output power is:

$$CF_P = 10 \text{ Log } 1.6[(B_{3dB})^2/SR] \qquad (5\text{-}1)$$

The peak output power is P_{Pi} + 10 Log 1.6[$B_{3dB}{}^2$/SR]. The CF for average power is:

$$CF_A = 10 \text{ Log } [B_{3dB}/(SR \text{ x } PRT)] \qquad (5\text{-}2)$$

The average output power is P_{Pi} + 10 Log [B_{3dB}/(SR x PRT)].

This technical memorandum defines the terms in these equations and the limits to which the equations are subject. NTIA performed measurements of swept frequency signals at the input and output of a variety of filter bandwidths as described in this technical memorandum and developed a general procedure for measuring the emissions of a system employing linear swept frequency techniques to provide an accurate measurement of the emissions. This is necessary to assess compatibility with other radio services. The correction factors and the measurement procedure described in this technical memorandum will be used in the development of the Best Practices Handbook.