

Appendix K

Radio Sources, Powers And Ensemble Signal Characteristics

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K.1 Introduction

This appendix provides technical details of some of the characteristics of radio sources which are important when assessing EMC. This work supports the threat definition in Section 2.1 of the main report.

K.2 Simple Radio Sources

The peak electric field strength at a distance d from a simple sinusoidal radiating source is given by [1, pp.196]

$$E_{\text{peak}} = \frac{\sqrt{60D_{\text{max}}P_{\text{av}}}}{d} \quad (\text{K.1})$$

where D_{max} is the maximum directive gain of the source and P_{av} is the average radiated power. For an idealised isotropic source $D_{\text{max}} = 1$ while for a half wave dipole $D_{\text{max}} = 1.64$. The root mean square field (RMS) field is

$$E_{\text{rms}} = \frac{E_{\text{peak}}}{\sqrt{2}} \quad (\text{K.2})$$

$$= \frac{\sqrt{30D_{\text{max}}P_{\text{av}}}}{d} \quad (\text{K.3})$$

where the RMS value of a signal $s(t)$ is defined by

$$x_{\text{rms}} = \langle x^2(t) \rangle \quad (\text{K.4})$$

$$\langle x(t) \rangle = \frac{1}{T_{\text{av}}} \int_0^{T_{\text{av}}} x(t) dt \quad (\text{K.5})$$

with the averaging interval, T_{av} , appropriately chosen. If T_{av} is not specified then a long term average $T_{\text{av}} \rightarrow \infty$ is generally assumed.

Peak Field (Vm ⁻¹)	RMS Field			
	Timeslot (Vm ⁻¹)	Frame (Vm ⁻¹)	Long Term (No DTX) (Vm ⁻¹)	Long Term (DTX) (Vm ⁻¹)
1	0.71	0.09	0.08	0.04
2	1.41	0.18	0.17	0.07
3	2.12	0.27	0.25	0.13
4	2.83	0.35	0.34	0.17
4.24	3.00	0.38	0.36	0.18
5	3.53	0.44	0.42	0.21
6	4.24	0.53	0.51	0.26
7	4.95	0.62	0.59	0.30
8	5.66	0.71	0.68	0.34
9	6.36	0.80	0.76	0.36
10	7.07	0.88	0.85	0.43
11	7.78	0.97	0.93	0.47
12	8.49	1.06	1.01	0.51
13	9.19	1.15	1.10	0.55
14	9.90	1.24	1.19	0.60
14.1	10.00	1.25	1.20	0.60
15	10.61	1.33	1.27	0.64

Table K.1: Peak and RMS field strengths for GSM using various averaging intervals for the RMS field. The last two columns compare the RMS power with DTX inactive and active.

K.3 Power In TDMA Systems

In TDMA radio systems different handsets are allocated different time slices in which to transmit. Time is divided into frames each of which is further subdivided into N_s timeslots of equal duration. This is sometimes called a 1: N_s TDMA system. A mobile handset transmits a burst of RF power in one of these timeslots.

For TDMA systems the peak transmitted power, P_{peak} , is defined as the average power transmitted over one TDMA burst. If the system uses power management then the peak power is defined using the maximum power level available (sometimes called maximum peak power). The peak field strength is defined as the maximum electric field over a single burst on the maximum power level. From K.1 we can therefore write

$$E_{\text{peak}} = \frac{\sqrt{60D_{\text{max}}P_{\text{peak}}}}{d}. \quad (\text{K.6})$$

The peak power when power management is in use is related to the maximum peak power E_{max} and the power level $l_i = 0, 1, \dots$ by

$$P_{\text{peak}} = P_{\text{max}} 10^{-l_i \Delta P / 10} \quad (\text{K.7})$$

where ΔP is the size of the power steps in decibels.

Average powers and RMS field strengths over longer time periods require careful definition. For example the RMS field over a TDMA frame is given by the RMS field over a burst ($E_{\text{peak}}/\sqrt{2}$) divided by the number of timeslots,

$$E_{\text{rms}} = \frac{E_{\text{peak}}}{\sqrt{2}N_s}. \quad (\text{K.8})$$

The average power of such $1:N_s$ TDMA systems is often quoted as

$$P_{av} = \frac{P_{peak}}{N_s}. \quad (\text{K.9})$$

This assumes that a single radio source only uses one timeslot per frame which is not necessarily the case. For example TETRA can use more than one of its four slots to increase the data rate for multimedia type services. Similarly UMTS UTRA TDD mode allows multiple timeslots to be used to vary the data rate and provide multiple services.

For averages over times scales greater than a frame power management, discontinuous transmission (DTX) and other system functions have an effect on the average power.

For GSM every twenty-sixth frame is silent to allow for compatibility with half rate transmission. The other twenty-five are generally in use if DTX is not active so the long term average power (ignoring power management) is $25/26$ times the average power in [K.9](#). However when DTX is active and no speech is present only noise samples and control signals are transmitted at less frequent intervals. If we assume that in a conversation a user speaks for half of the time then the long term average power in DTX mode is approximately half that without DTX [\[2\]](#) (for a more detailed estimate see [\[2\]](#)).

Table [K.1](#) gives a list of peak fields for GSM900 compared to RMS fields over different time intervals with and without DTX. Note that the peak fields can be much greater than the long term average fields.

K.4 Low Frequency Components In TDMA Systems

The electric field at \mathbf{r} due to a TDMA radio source j of peak power P_j at position \mathbf{r}_j can be modelled as [\[2\]](#)

$$\mathbf{E}_j(\mathbf{r}, t) = \frac{\sqrt{90D_{\max}P_j}}{|\mathbf{r} - \mathbf{r}_j|} \cdot \text{pramp}(t_d) \cdot \text{tdma}(t_d) \cdot s_j(t) \cdot \mathbf{e}_j(\hat{\boldsymbol{\rho}}_j, \hat{\boldsymbol{\rho}}_j) \quad (\text{K.10})$$

where

$$t_d = t - \frac{1}{c} |\mathbf{r} - \mathbf{r}_j| \quad (\text{K.11})$$

$$\boldsymbol{\rho}_j = \mathbf{r} - \mathbf{r}_j \quad (\text{K.12})$$

$$\hat{\boldsymbol{\rho}}_j = \frac{\mathbf{r} - \mathbf{r}_j}{|\mathbf{r} - \mathbf{r}_j|} \quad (\text{K.13})$$

$$\mathbf{e}_j(\hat{\boldsymbol{\rho}}_j, \hat{\boldsymbol{\rho}}_j) = \hat{\boldsymbol{\rho}}_j - (\hat{\boldsymbol{\rho}}_j \cdot \hat{\boldsymbol{\rho}}_j) \hat{\boldsymbol{\rho}}_j. \quad (\text{K.14})$$

Here $\hat{\boldsymbol{\rho}}_j$ is the polarisation vector of source j , $\text{pramp}(t)$ represents the ramping up and down of the RF power during bursts, $\text{tdma}(t)$ contains the TDMA structure and $s_j(t)$ is the transmitted signal. Note that here we are using the non-isotropic polarisation term [K.14](#) for a infinitesimal dipole which has a gain of $D_{\max}1.5$. If we ignore the modulation of the source then the signal term $s_j(t)$ can be taken as

$$s_j(t) = \cos(\omega_j t) \quad (\text{K.15})$$

A model for a GMSK modulated signal can be found in [Appendix I.2](#).

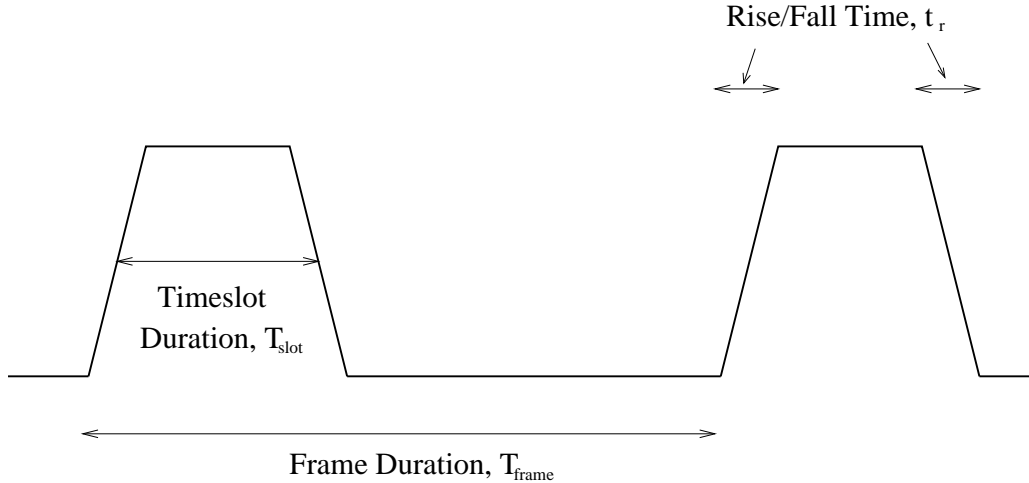


Figure K.1: Trapezoidal pulse train representation of the RF power bursting in TDMA systems.

The RF power bursts are represented by

$$\text{pramp}(t) = \sum_{k=-\infty}^{\infty} p(t) \otimes \delta(t - kT_{\text{frame}}) \quad (\text{K.16})$$

where T_{frame} is the duration of a TDMA frame and $p(t)$ is the profile of the RF burst. A particular form for $p(t)$ in GSM is given in [Appendix G.8](#). A simpler approximation is to use a trapezoidal pulse train as shown in [Figure K.1](#). This RF bursting imparts a low frequency component onto the spectrum of the signal from TDMA sources which also appears as sidebands of the RF carrier. The spectrum of the RF bursting envelope due to the trapezoidal pulse train can be calculated by Fourier analysis [[1](#), ???].

[Figure K.2](#) shows the spectrum of the RF bursting envelope of GSM parameters. The fundamental frequency is just the frame rate of the TDMA (217 Hz in this case). Every eighth harmonic is absent due to the duty cycle of 1/8. There is significant energy in the spectrum up to 10 kHz. [Figure K.3](#) shows a similar spectrum for TETRA which has a much lower frame rate of 17 Hz. In this case every fourth harmonic is absent. As noted above in TETRA more than one timeslot can be used by a single transmitter allowing different types of envelope to be generated.

The $\text{tdma}(t)$ term in [K.10](#) models the TDMA structure of the signal. Detailed expressions for $\text{tdma}(t)$ can be found in [[2](#)]. For example when DTX is active the timeslot is not active in every frame. This causes very low frequency components in the spectrum down to 2 Hz [[3](#)].

K.5 Ensemble Signals

Consider a number of sinusoidal sources $j = 1, \dots, N_P$ of frequency $\omega_j/2\pi = f_j$ transmitting signals of amplitude a_j . The signal from each source can be written

$$s_j(t) = a_j \cos(\omega_j t + \phi_j). \quad (\text{K.17})$$

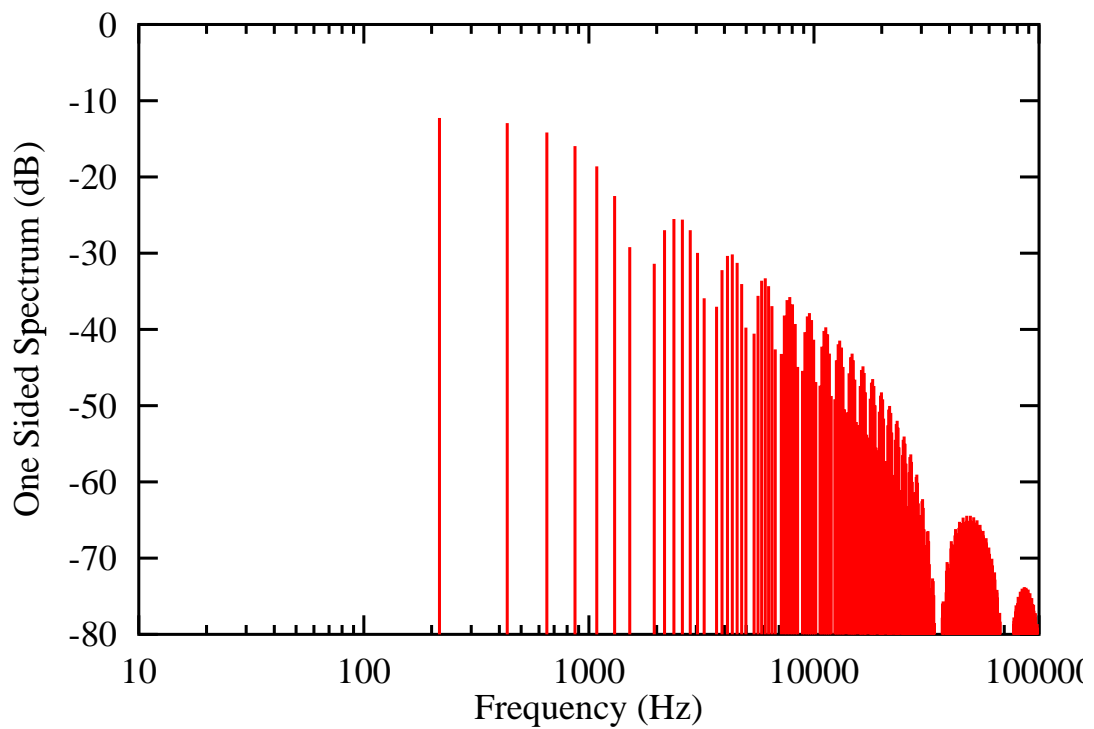


Figure K.2: Spectrum of power bursting envelope in GSM.



Figure K.3: Spectrum of power bursting envelope in TETRA.

This can be viewed as a simplification of (K.10) within a single RF burst where a_j is determined by the power, propagation loss and polarisation factors. The total, or ensemble, signal is

$$s(t) = \sum_{j=1}^{N_P} a_j \cos(\omega_j t + \phi_j) \quad (\text{K.18})$$

and the peak signal and RMS signal strengths calculated from this are

$$s_{\text{peak}} = \sum_{j=1}^{N_P} a_j \quad (\text{K.19})$$

$$s_{\text{rms}} = \sqrt{\frac{\sum_{j=1}^{N_P} a_j^2}{2}}. \quad (\text{K.20})$$

If we assume all the sources have amplitude a then these equations reduce to

$$s_{\text{peak}} = a N_P \quad (\text{K.21})$$

$$s_{\text{rms}} = a \sqrt{\frac{N_P}{2}} \quad (\text{K.22})$$

Figure K.4 shows an ensemble signal consisting of five sinusoidal components of unit amplitude with equally spaced frequencies (5 MHz separation) in the GSM900 band.

The ensemble signal has an overall background corresponding roughly to the RMS level, s_{peak} , with periodic pulses of amplitude s_{peak} . The width of these pulse is determined by the total bandwidth of the sources,

$$B_T = \max [f_i] - \min [f_i], \quad (\text{K.23})$$

and given by

$$PW = \frac{1}{B_T}. \quad (\text{K.24})$$

Figure K.5 shows the dependence of the pulse width on the total bandwidth for a range of bandwidths characteristic of most mobile communication systems. Pulses as short as a few tens of nanoseconds are possible with sources distributed over 25 MHz.

The pulse repetition frequency (PRF) depends on the dispositions of sources over the total bandwidth and is generally inversely related to the lowest frequency component in the ensemble signal

$$PRF = \min [f_i - f_j]. \quad (\text{K.25})$$

If we assume that N_P sources are uniformly distributed over the total bandwidth B_T then the frequency spacing is equal to the PRF and given by

$$PRF = \frac{B_T}{N_P - 1}. \quad (\text{K.26})$$

Figure K.6 shows the PRF as a function of the total signal bandwidth and the number of sources. In general the PRF decreases as the number of sources increases. The duty cycle of the pulses, DC, depends only on the number of sources:

$$DC = \frac{1}{N_P - 1} \quad (\text{K.27})$$

This is shown in Figure K.7.

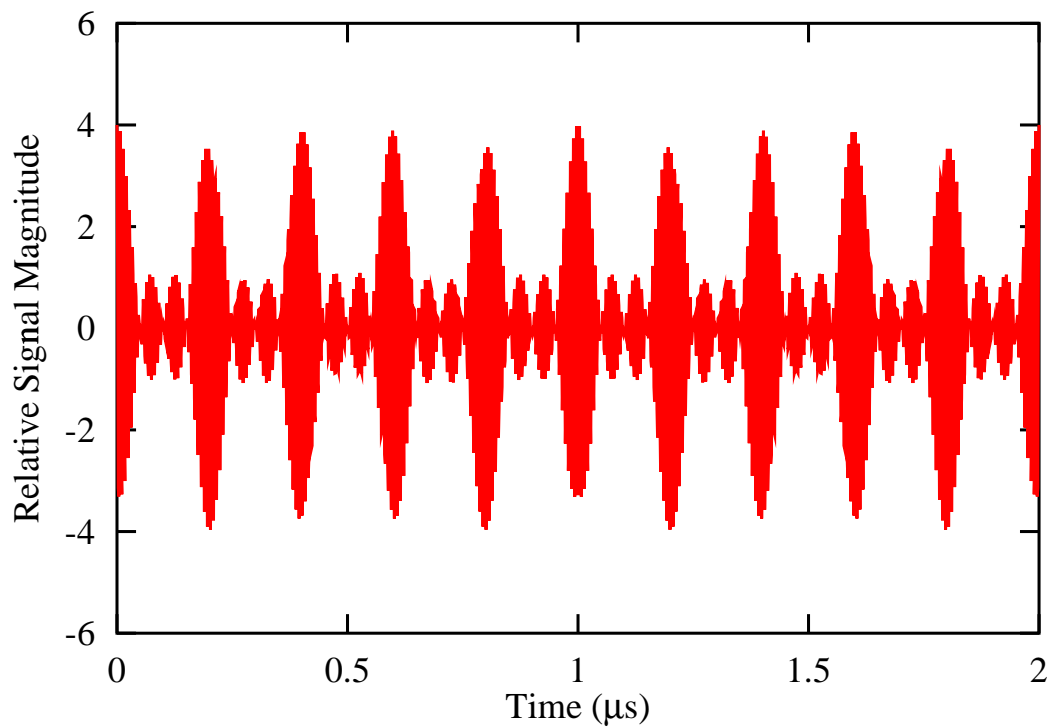


Figure K.4: Example of an ensemble signal with five sources of frequency 890, 895, 900, 905 and 910 MHz.

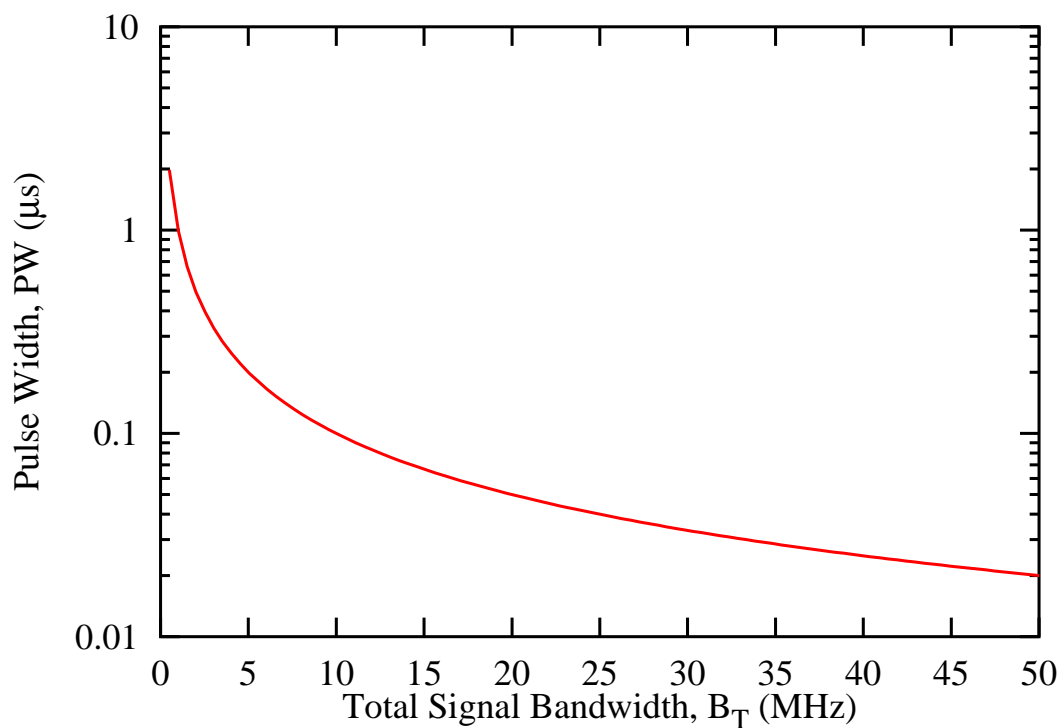


Figure K.5: Width of pulses in ensemble signal as a function of the total signal bandwidth.

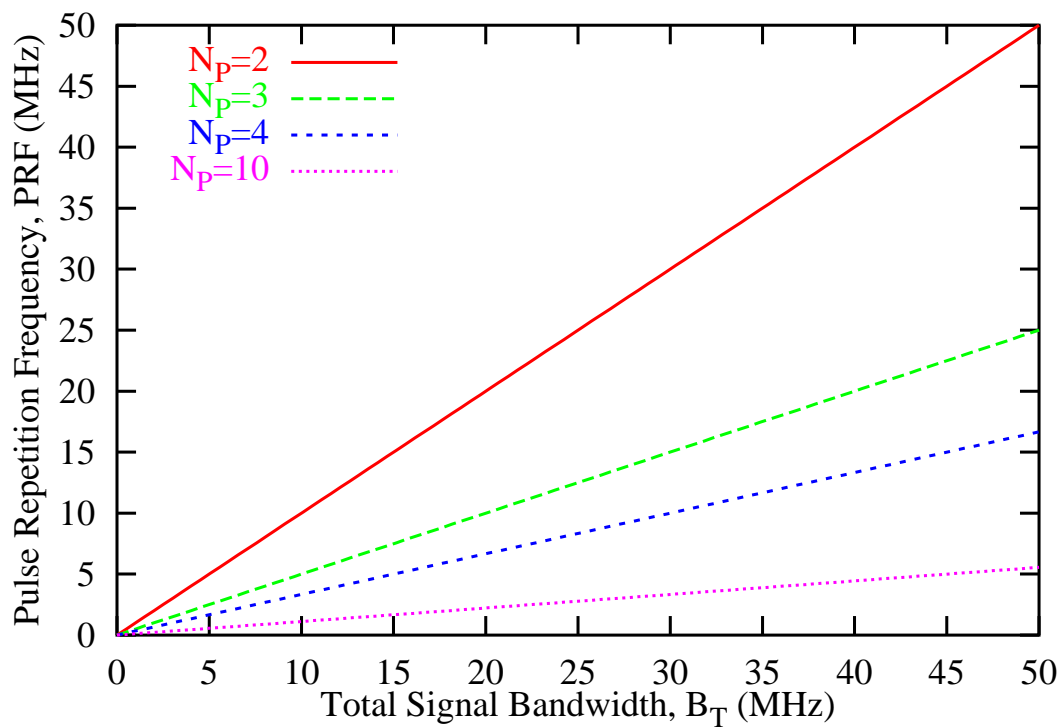


Figure K.6: Repetition frequency of pulses in ensemble signal as a function of the total signal bandwidth and number of sources (uniformly spaced carriers).

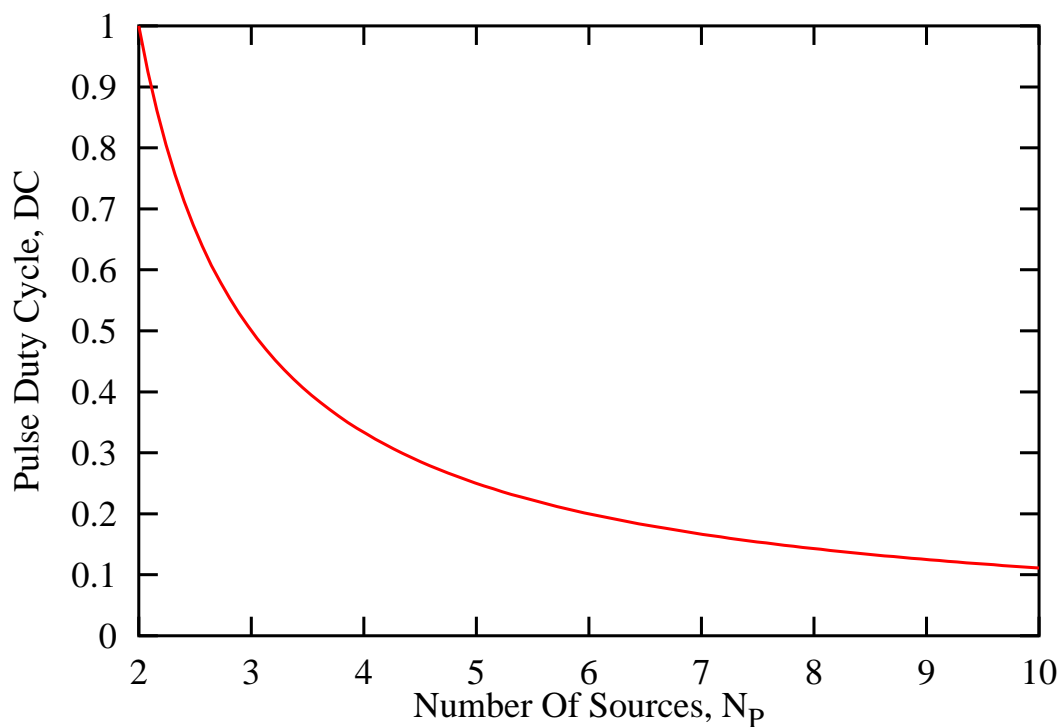


Figure K.7: Duty cycle of pulses in ensemble signal as a function of the number of sources.

References

- [1] C R Paul *Introduction To Electromagnetic Compatibility*, Wiley Series In Microwave And Optical Engineering, John Wiley, 1992.
- [2] G F Pedersen, *Amplitude Modulated RF Fields Stemming From A GSM/DCS-1800 Phone*, Wireless Networks, No. 3, 1997, pp. 489-498.
- [3] F Han and J Nuutinen, *Analysis Of Spurious Spectrum Due To RF Bursting Signals In TDMA-Based Wireless Communication Systems*, IEEE Int. Symp. Electromag. Compat., Denver, 1998, pp.393-398.