# The Effects of PDFs on the Line-to-Line Voltage and Noise Generated by PWM Inverters

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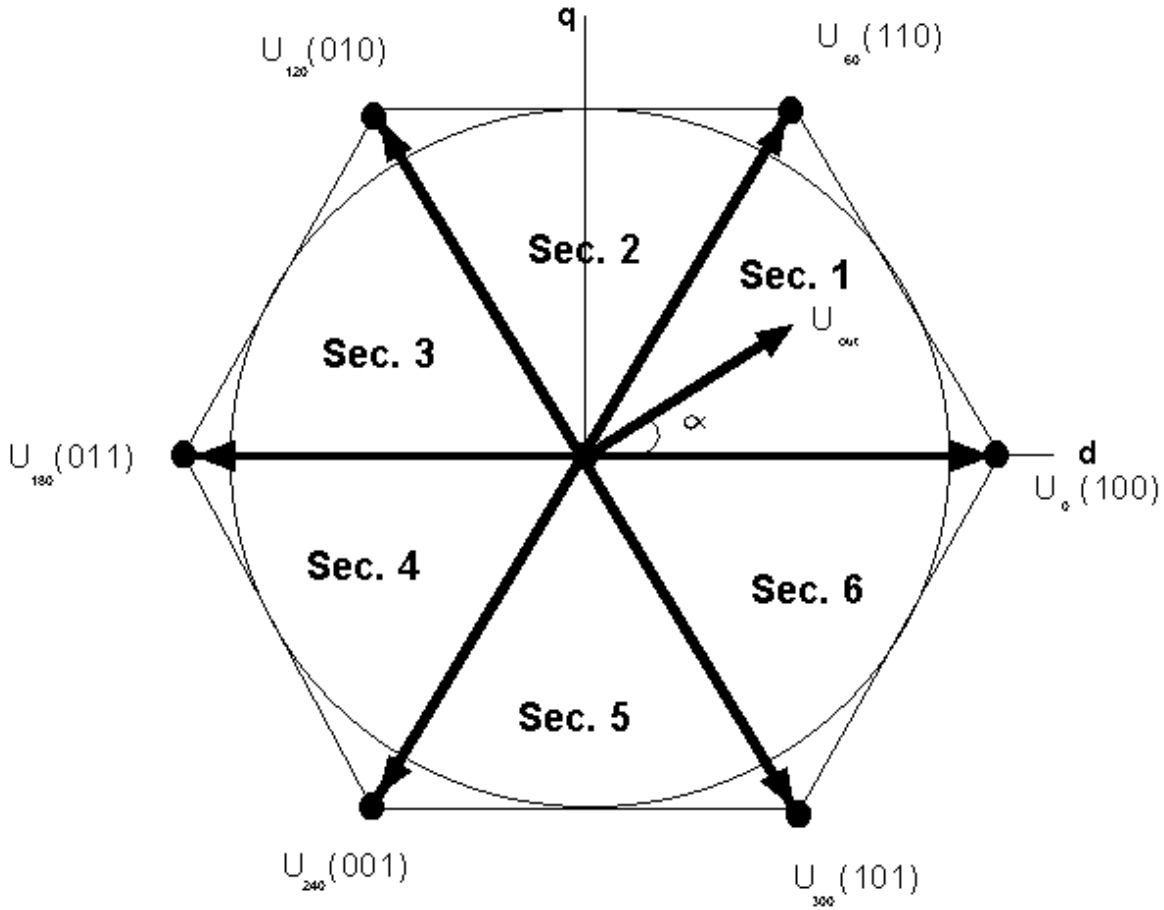
# OBJECTIVES

- **Limited-Pool RPWM**
  *** SVPWM**
  *** TMS320C240 implementation**

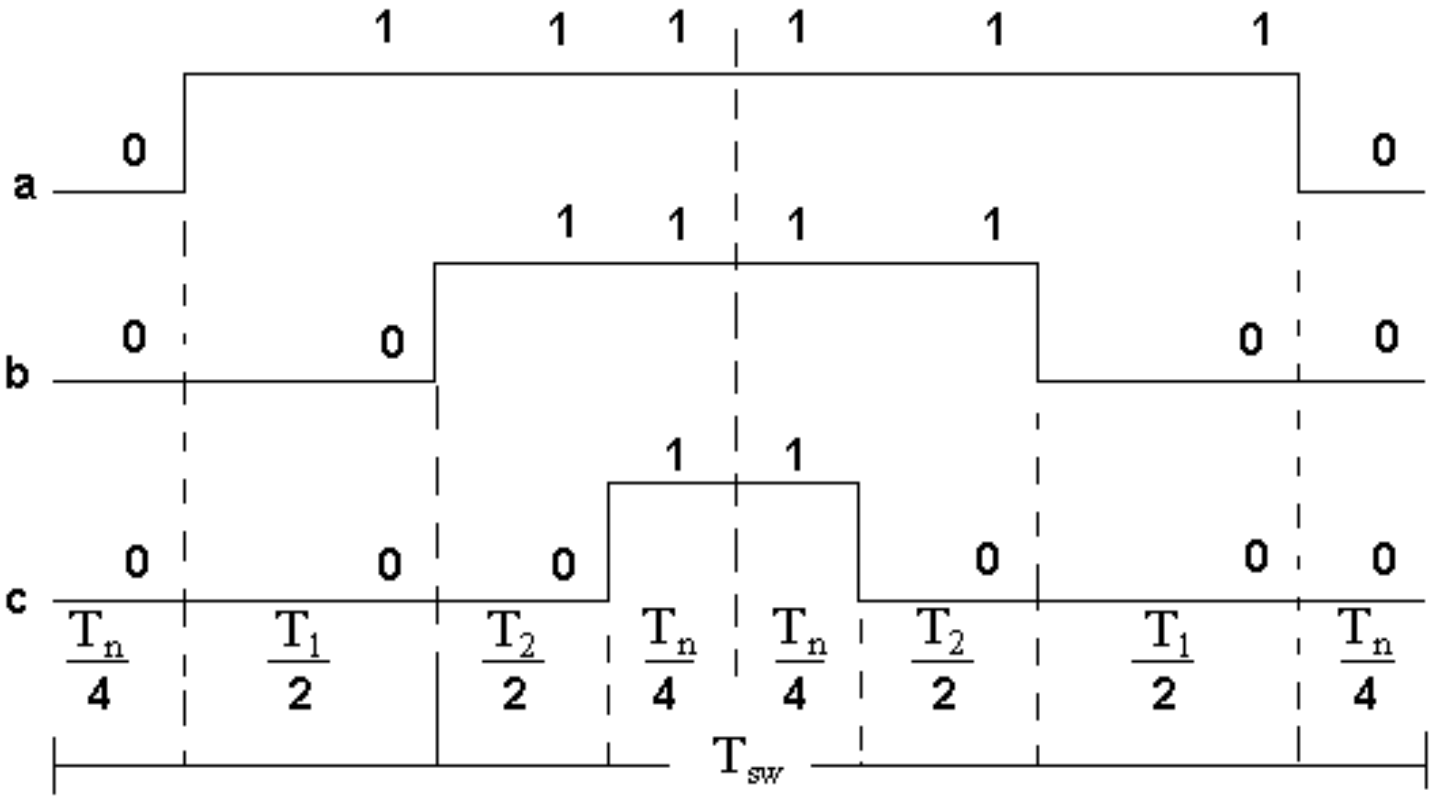
- **Effects of Different PDFs upon:**
  *** the line-to-line voltage spectrum, and**
  *** acoustic noise spectrum**



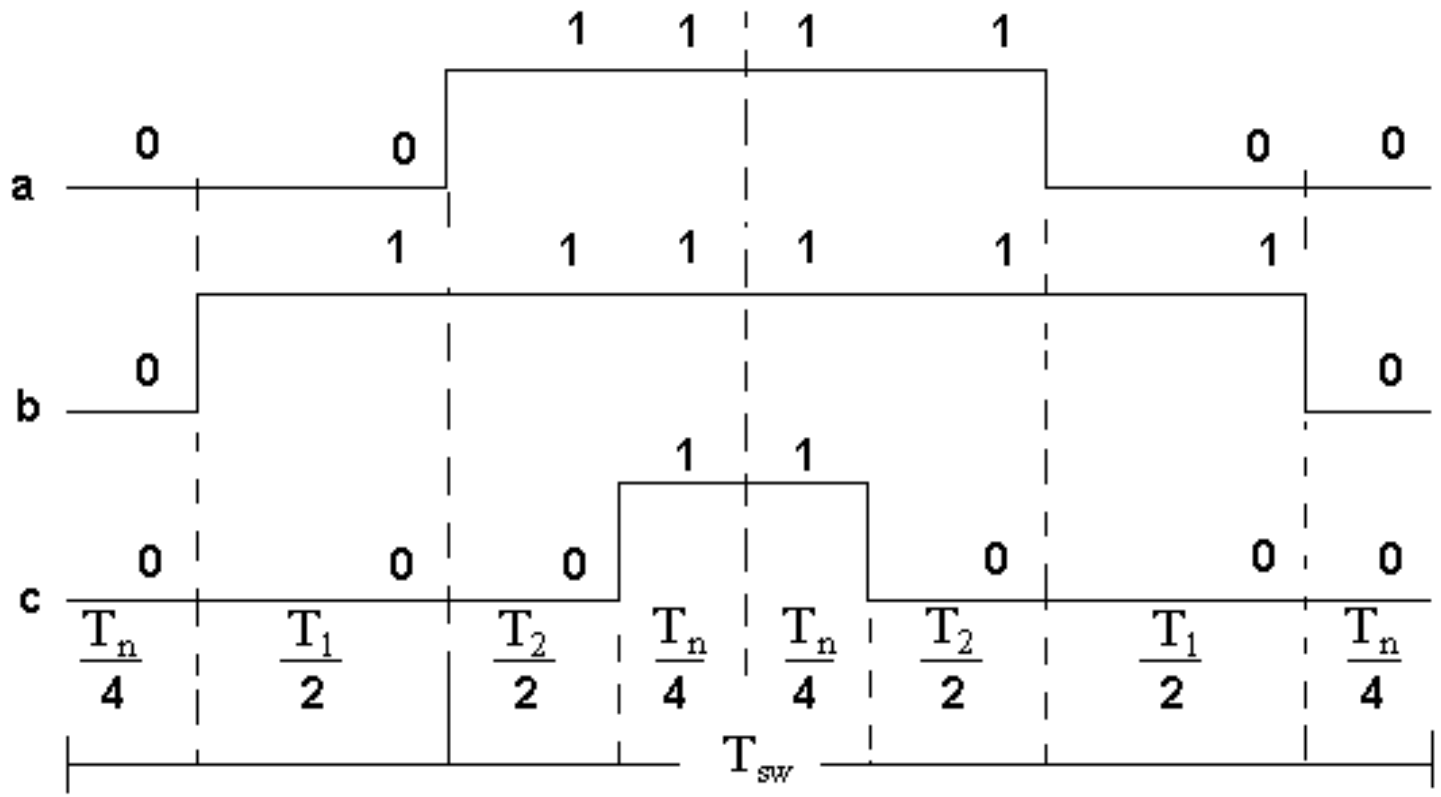
# SVPWM
# Estimating the rotating vector $U_{out}$



# SVPWM SEQUENCE
# one period ($T_{sw}$) for sector 1



# SVPWM SEQUENCE
# one period ($T_{sw}$) for sector 2



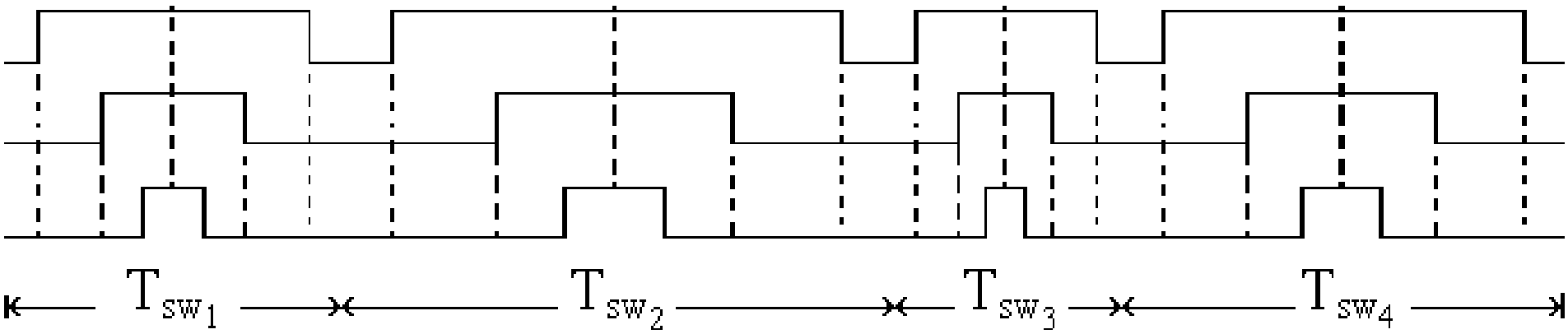
# SIDE EFFECT OF SVPWM

- **High harmonic clusters in the line-to-line voltage spectrum around each integer multiple of the switching frequency**

- **These harmonic clusters are the source of the tonal clusters in the noise spectrum**



# SOLUTION: RPWM
# ($T_{sw}$ changes randomly)



- **Classical RPWM**
  - **An economical solution for acoustic noise reduction by mean of spreading the harmonic clusters over the spectral range**
  - **Number of switching frequencies is large**
  - **Impractical for closed-loop systems**
- **Limited-pool RPWM**
  - **Performs as well as the classical RPWM when its switching frequencies are carefully selected**
  - **Only 5 or 6 switching frequencies**
  - **Preferable over the classical RPWM for closed-loop systems**



# SELECTING THE POOL SWITCHING FREQUENCIES

- **Common-Multiple Deviation (CMD)**

$$d(f) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left[\frac{f}{f_i} - round\left(\frac{f}{f_i}\right)\right]^2}$$



# POOL SPECIFICATIONS

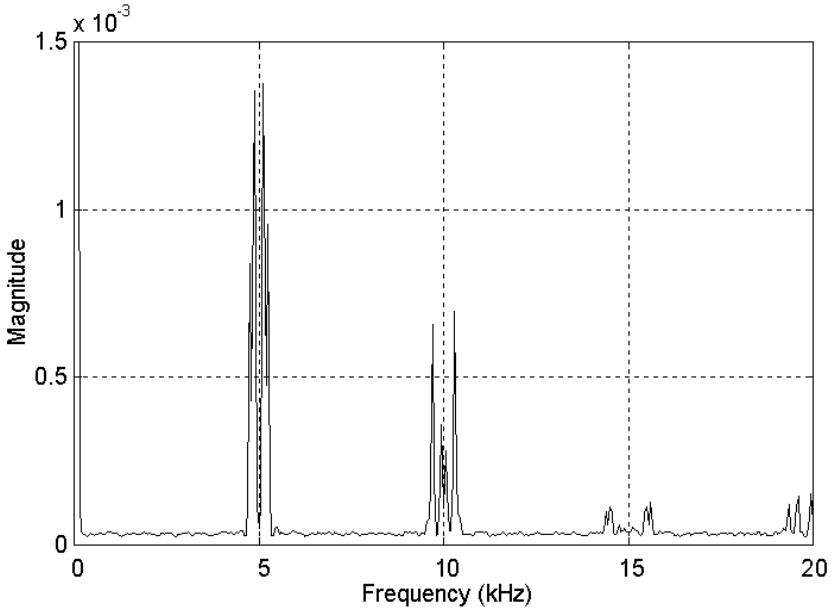
- **Switching range: 3.5 - 7.5 kHz**
- **Pool size: 5 frequencies**
- **Spectral range: 0 - 20 kHz**

# CMD-BASED BEST POOL

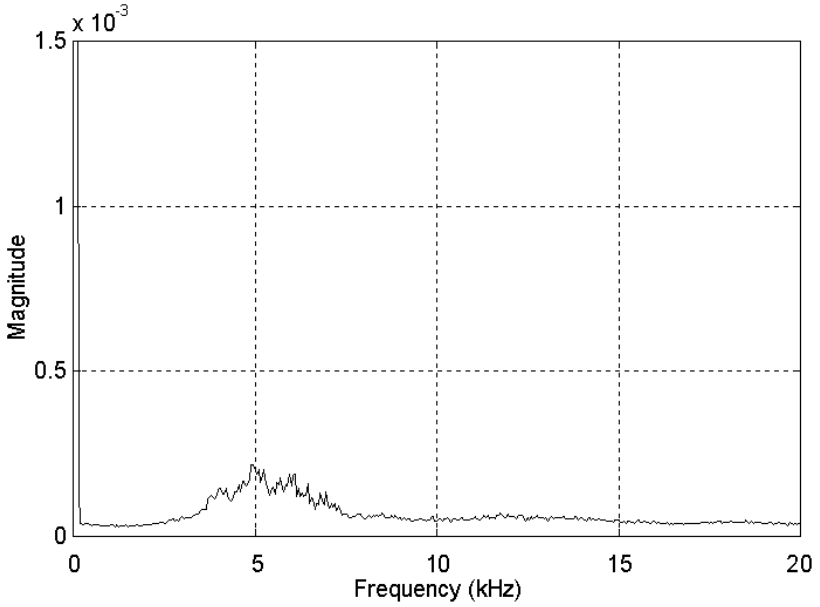
**3676, 4664, 5733, 6443, 7267 Hz**



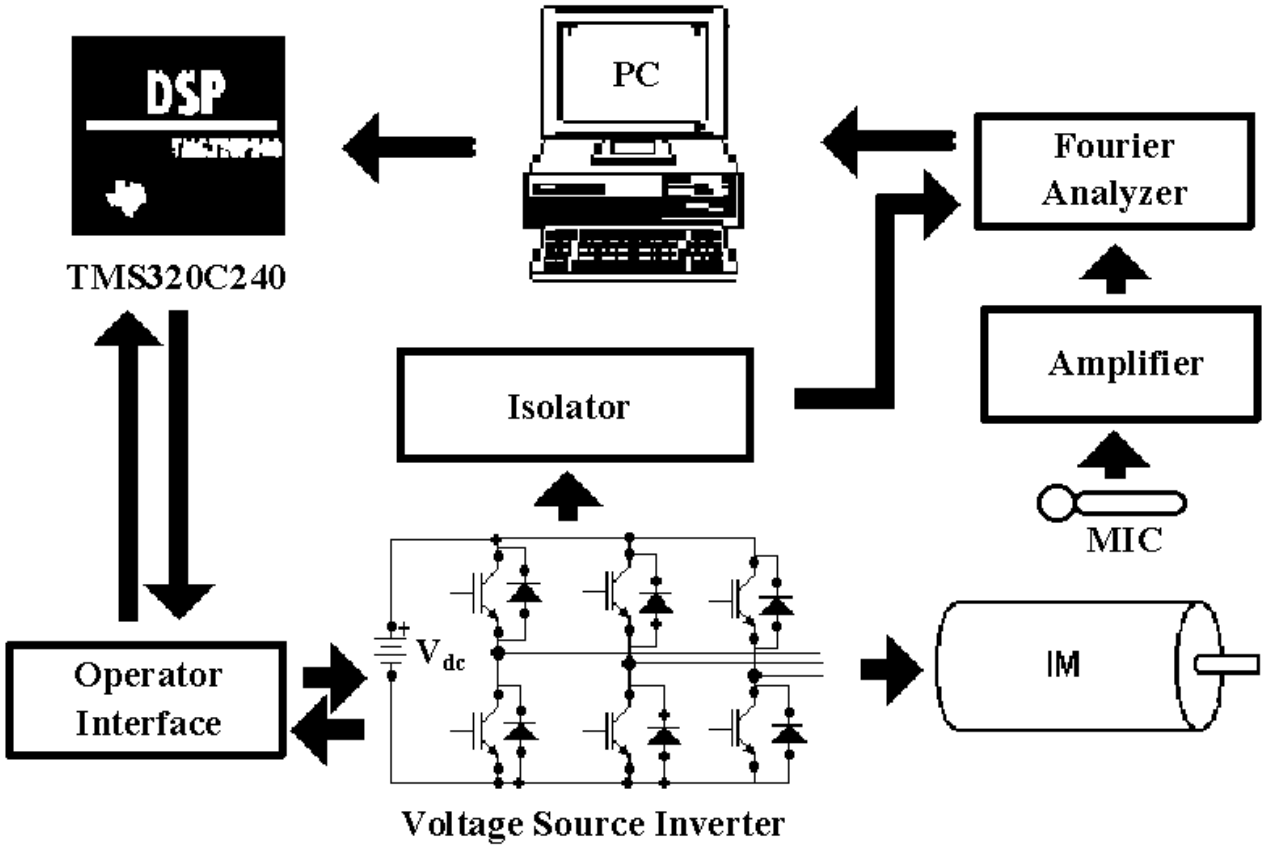
- **Voltage spectrum of the SVPWM**




- **Voltage spectrum of the limited-pool RPWM**



# EXPERIMENTAL SETUP



# INVESTIGATED PDFs

- **Uniform**
- **Trapezium**
- **Pink hyperbolic**
- **Laplacian**
- **Cauchy**
- **Rayleigh**
- **Maxwell**
- **Arbitrary selected**



# CALCULATED PROBABILITIES

| PDF | $P_{l\_p}(f_1)$ | $P_{l\_p}(f_2)$ | $P_{l\_p}(f_3)$ | $P_{l\_p}(f_4)$ | $P_{l\_p}(f_5)$ |
|---|---|---|---|---|---|
| **Uniform** | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| **Trapezium** | 0.1323 | 0.1679 | 0.2063 | 0.2319 | 0.2616 |
| **Pink hyperbolic** | 0.2852 | 0.2248 | 0.1829 | 0.1627 | 0.1443 |
| **Laplacian** | 0.2741 | 0.2290 | 0.1886 | 0.1657 | 0.1427 |
| **Cauchy** | 0.2724 | 0.2292 | 0.1888 | 0.1661 | 0.1434 |
| **Rayleigh** | 0.1860 | 0.2060 | 0.2107 | 0.2053 | 0.1921 |
| **Maxwell** | 0.1726 | 0.2117 | 0.2215 | 0.2102 | 0.1841 |
| **Arbitrary** | 0.2460 | 0.1563 | 0.0977 | 0.2070 | 0.2930 |



# LINEAR CONGRUENTIAL GENERATOR

$$x_{i+1} = [Mult * x_i + Inc] \bmod (m)$$

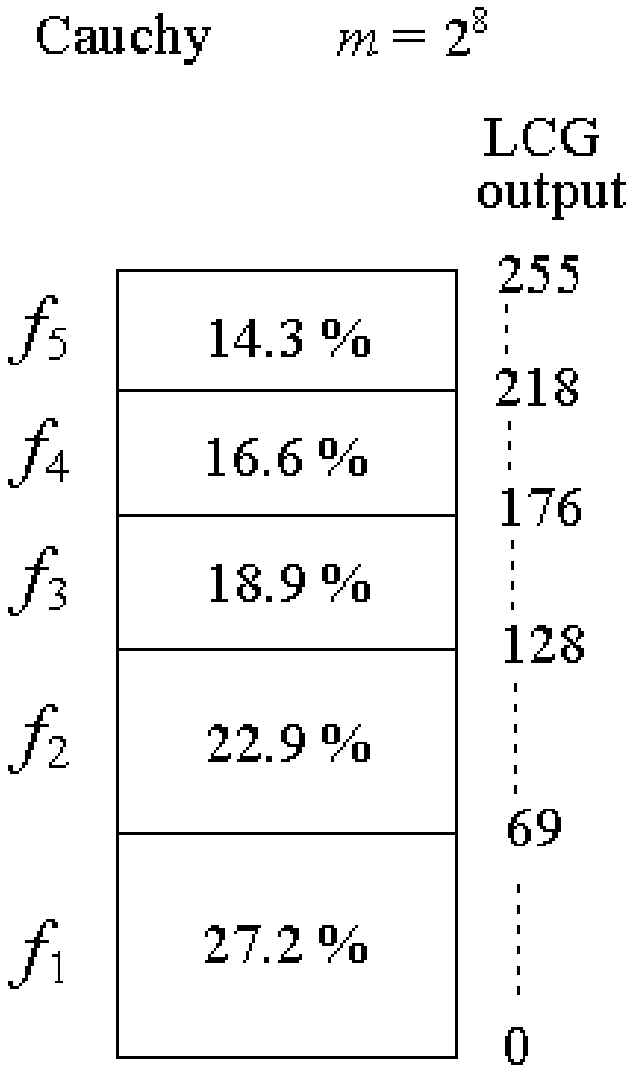
$x_{i+1}$ is the remainder of $\dfrac{\lfloor \text{Mult} * x_i + \text{Inc} \rfloor}{m}$

If m is a power of 2, then

$$x_{i+1} = [Mult * x_i + Inc] \text{ AND } m$$

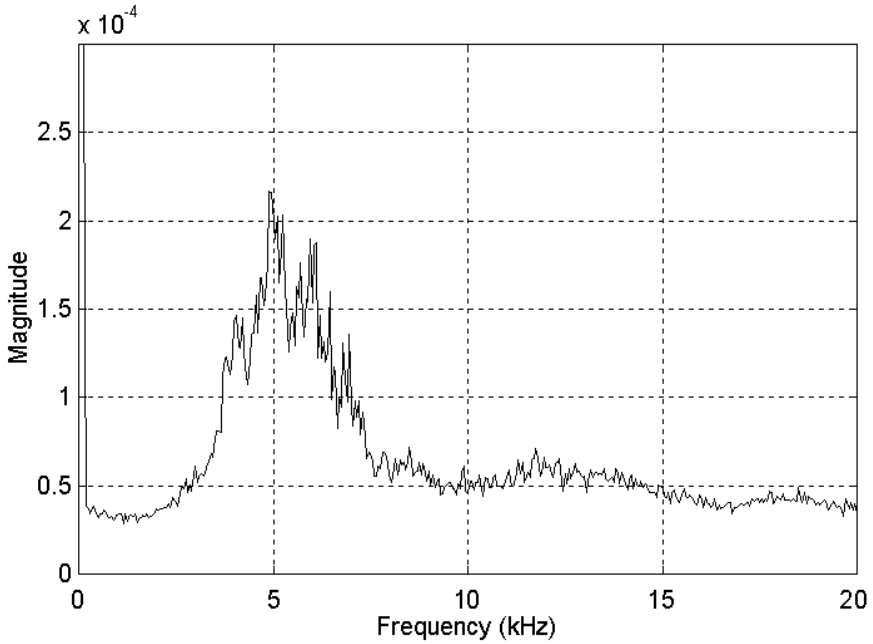


# ON-LINE FREQUENCY SELECTION

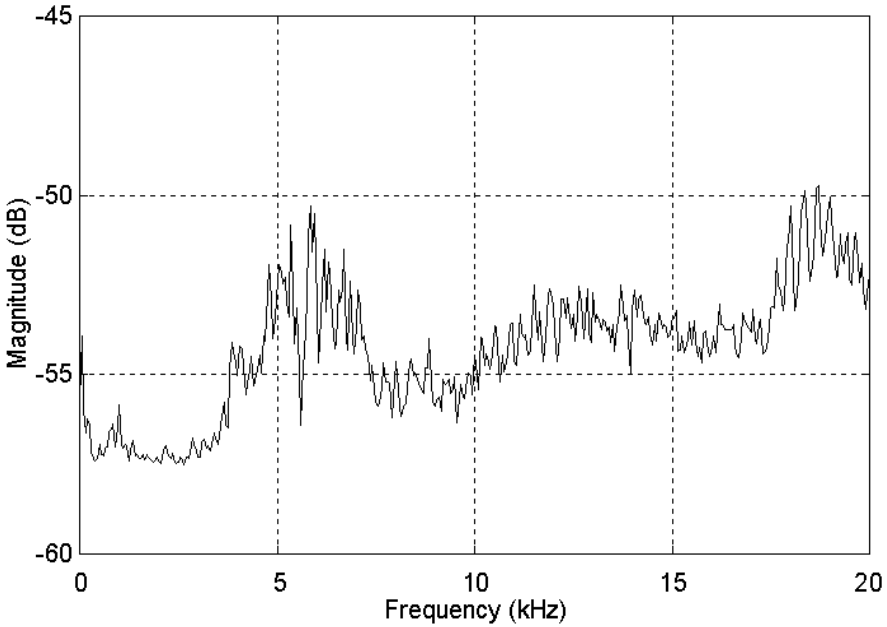


# UNIFORM

## Voltage Spectrum

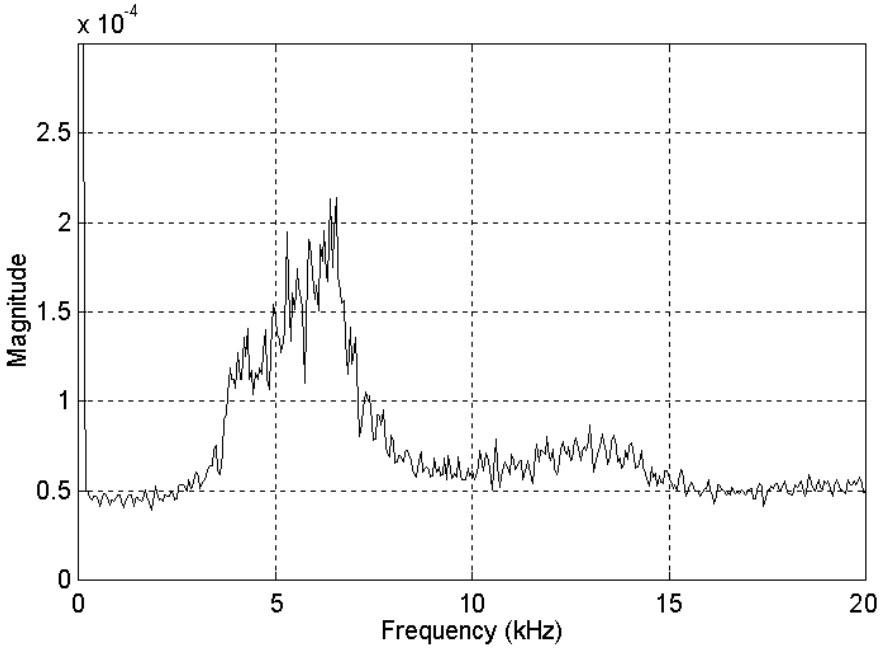



## Noise Spectrum

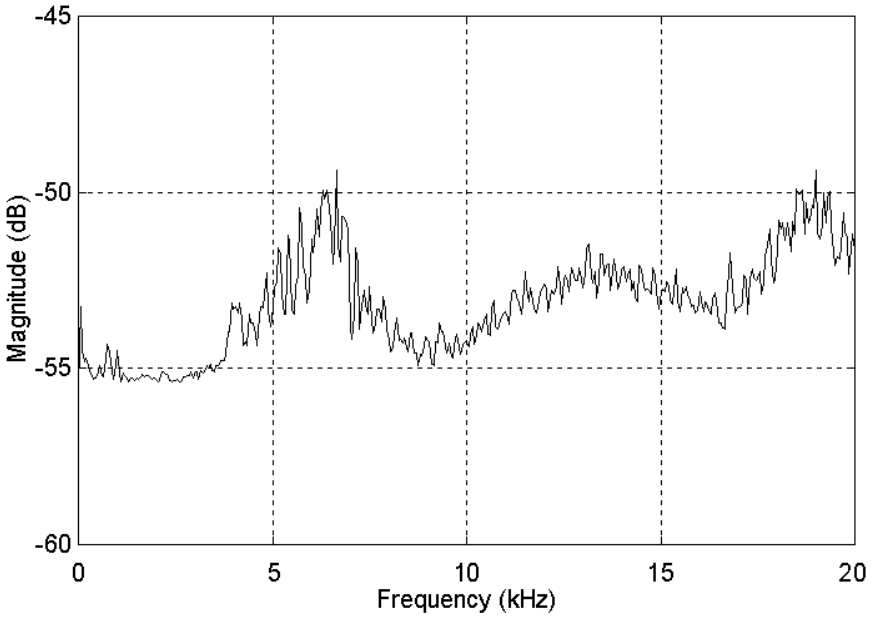


# TRAPEZIUM

## Voltage Spectrum

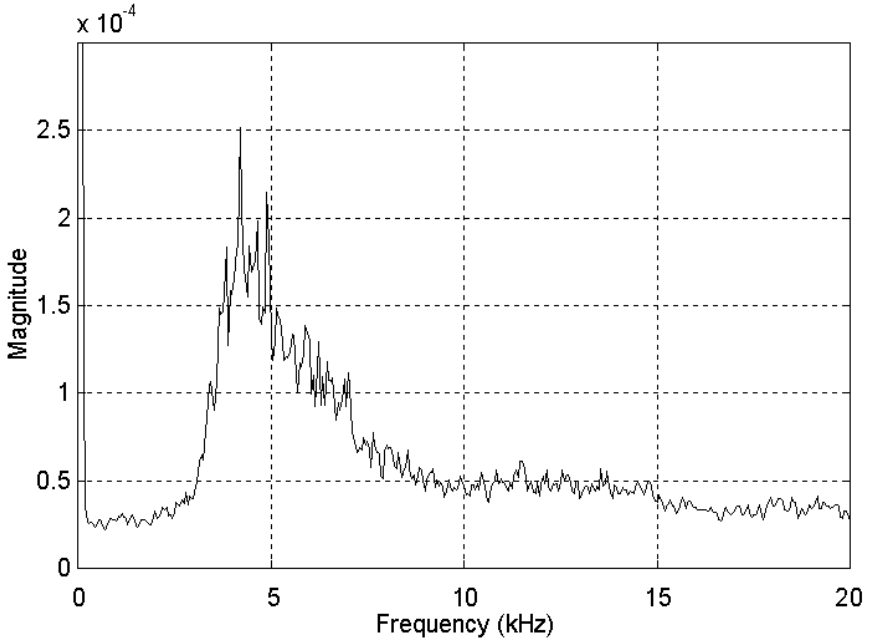



## Noise Spectrum

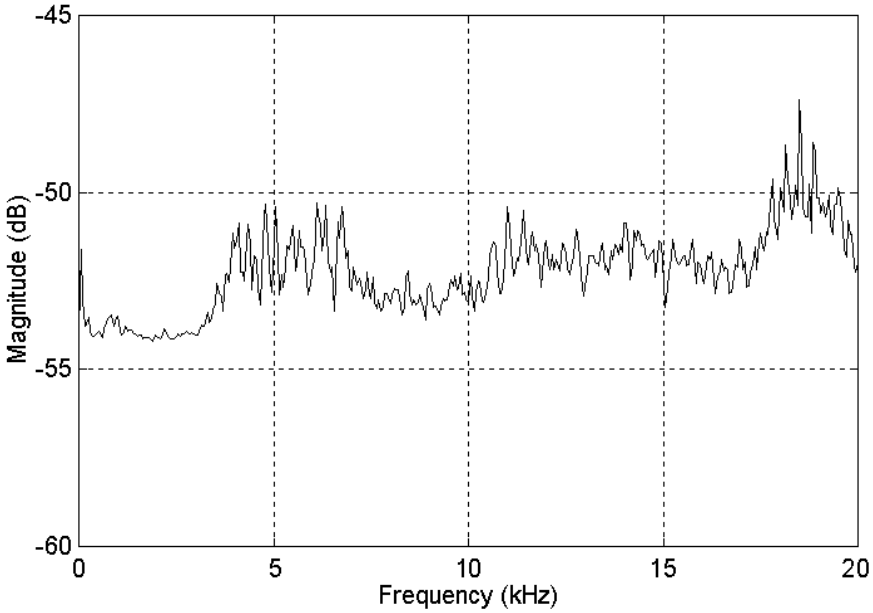


# PINK HYPERBOLIC

## Voltage Spectrum

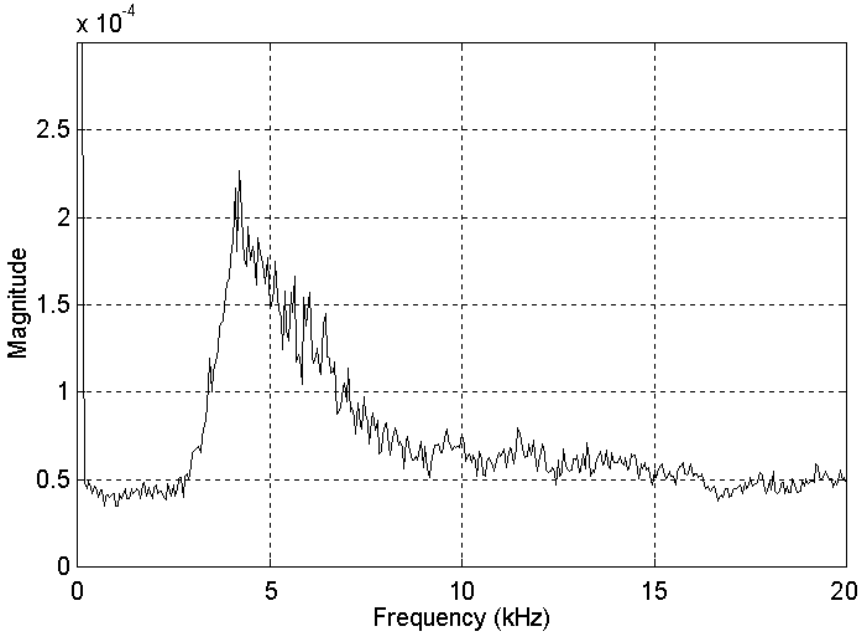



## Noise Spectrum

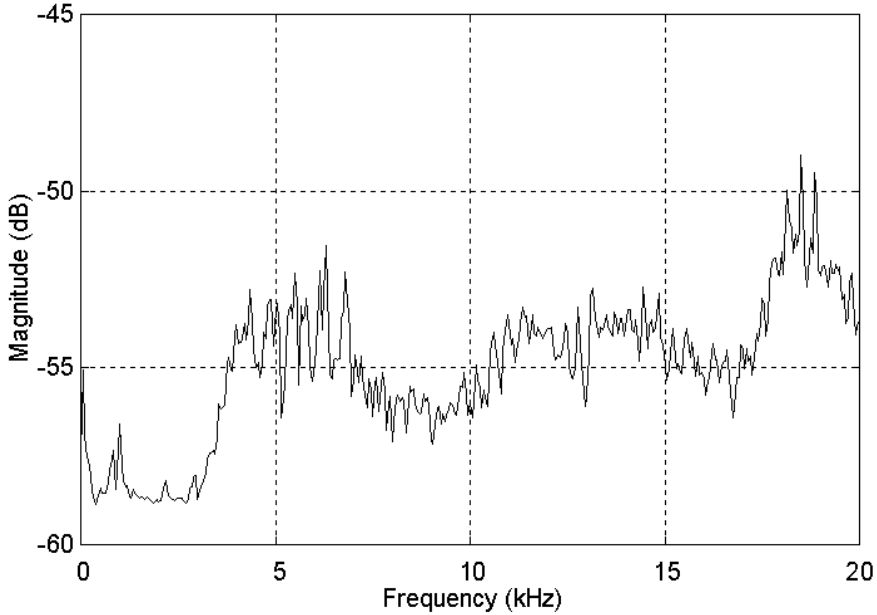


# LAPLACIAN

## Voltage Spectrum

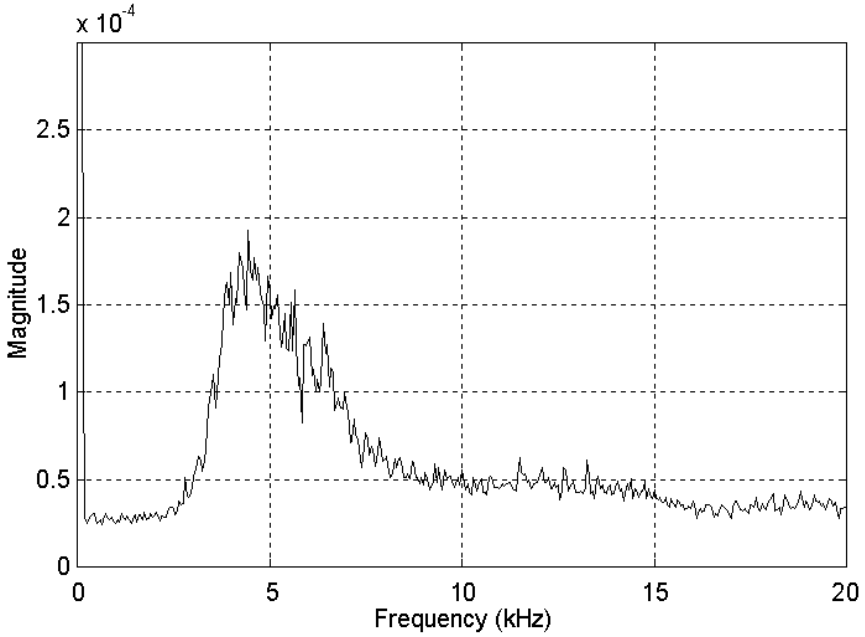



## Noise Spectrum

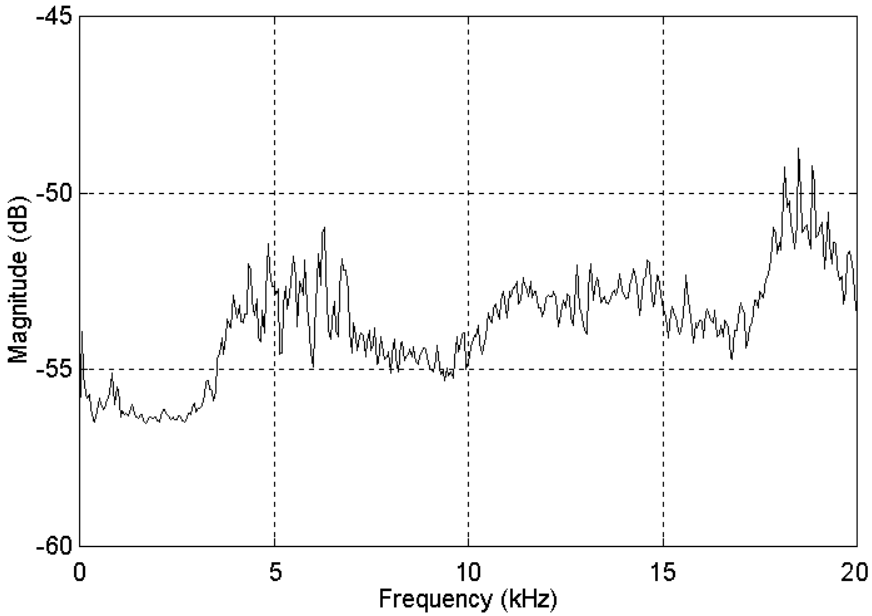


# CAUCHY

## Voltage Spectrum

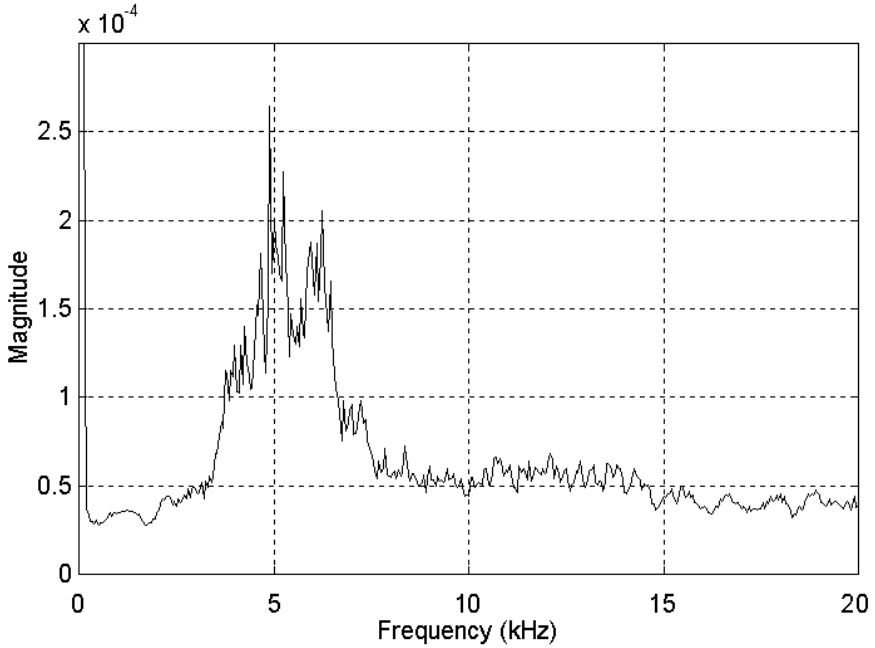



## Noise Spectrum

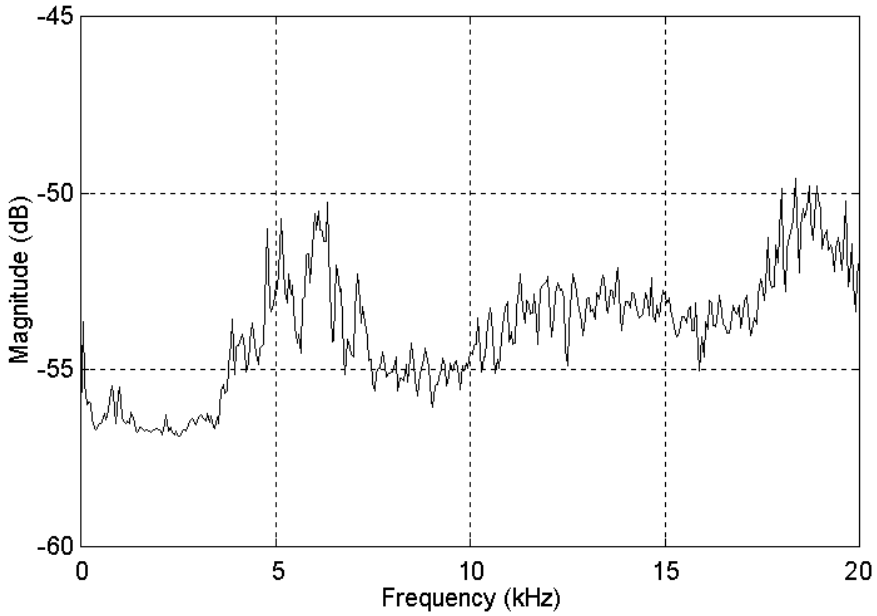


# RAYLEIGH

## Voltage Spectrum

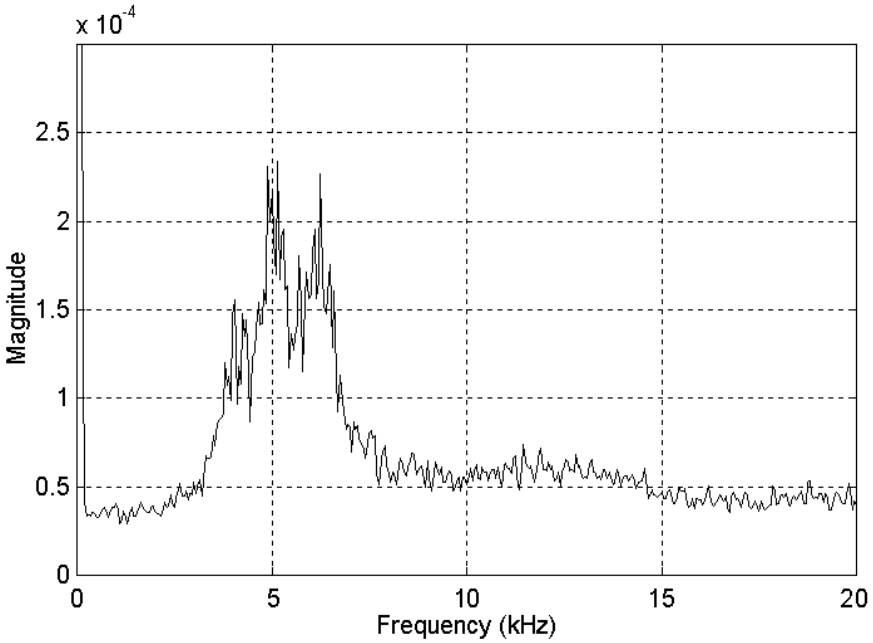



## Noise Spectrum

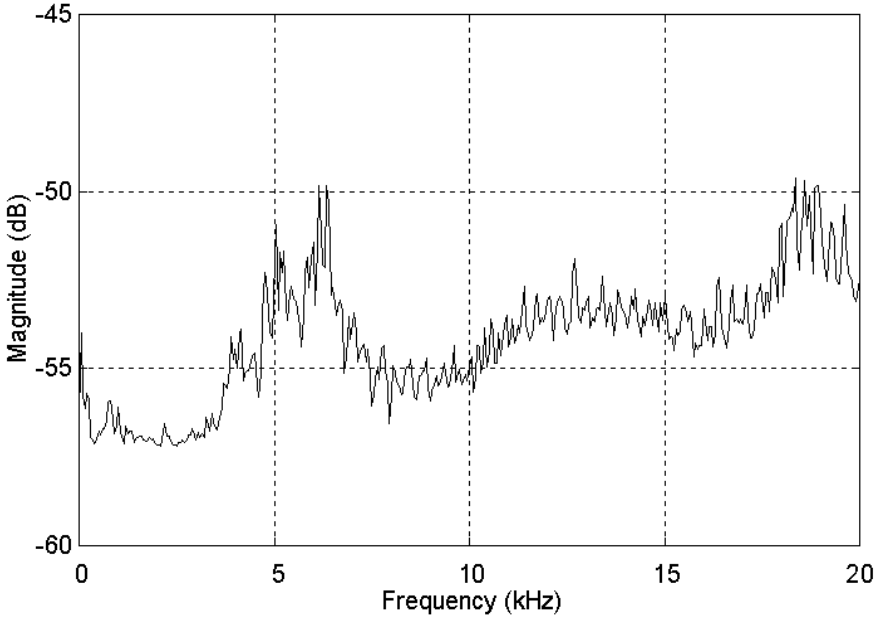


# MAXWELL

## Voltage Spectrum

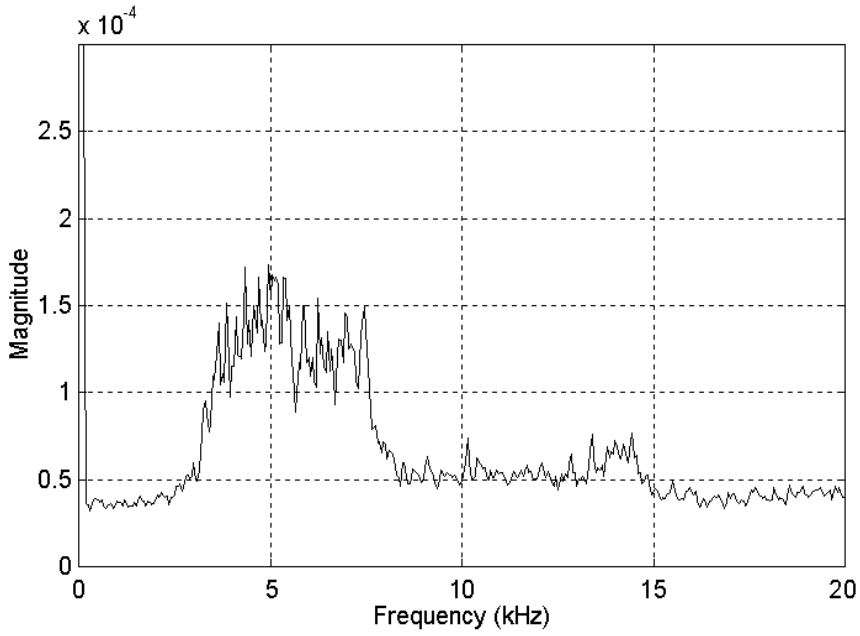



## Noise Spectrum

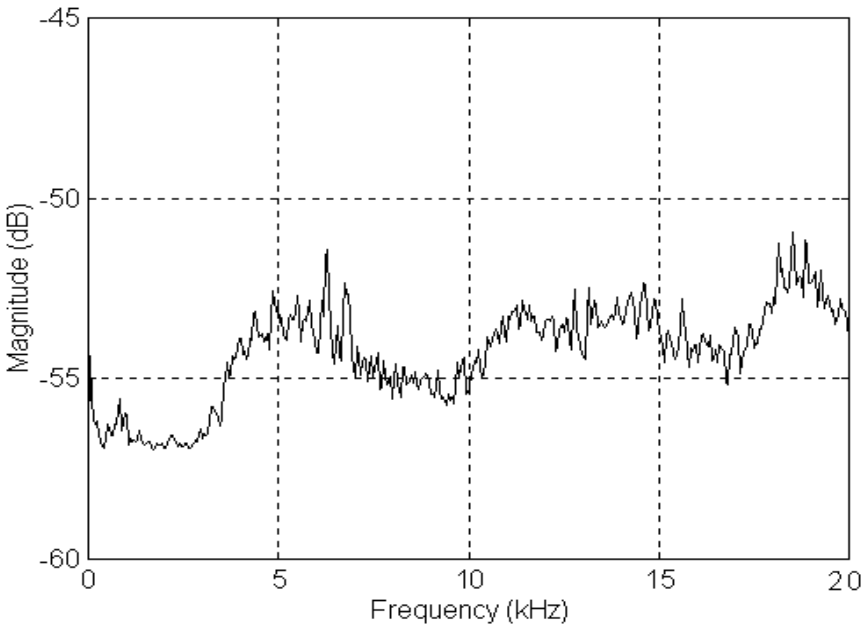


# ARBITRARY SELECTED

## Voltage Spectrum

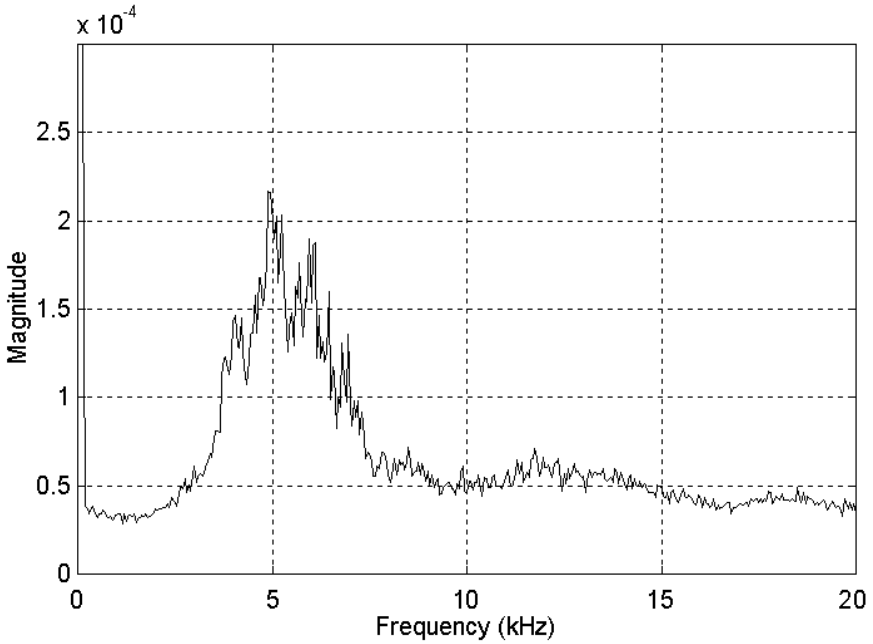



## Noise Spectrum

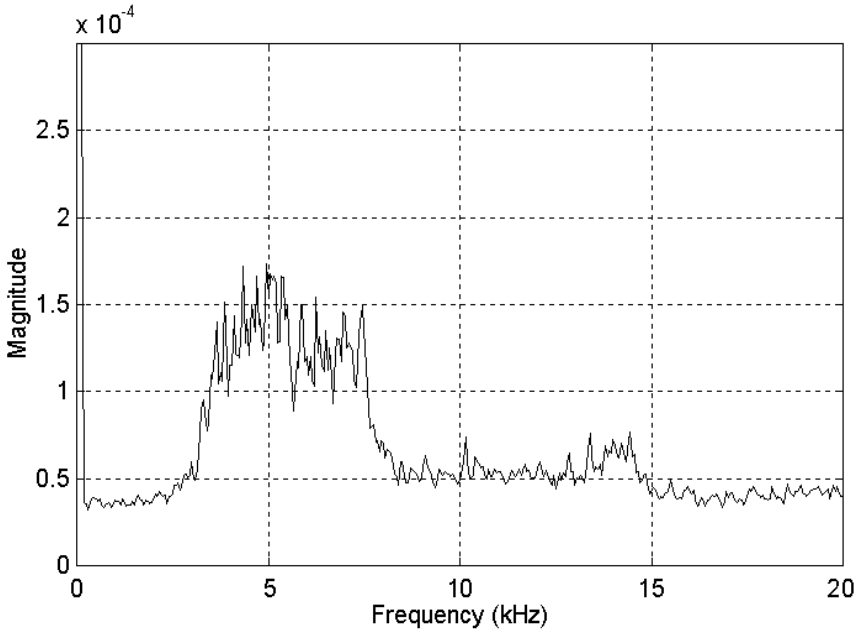


# LINE VOLTAGE SPECTRUM

## Uniform PDF




## Arbitrary selected PDF

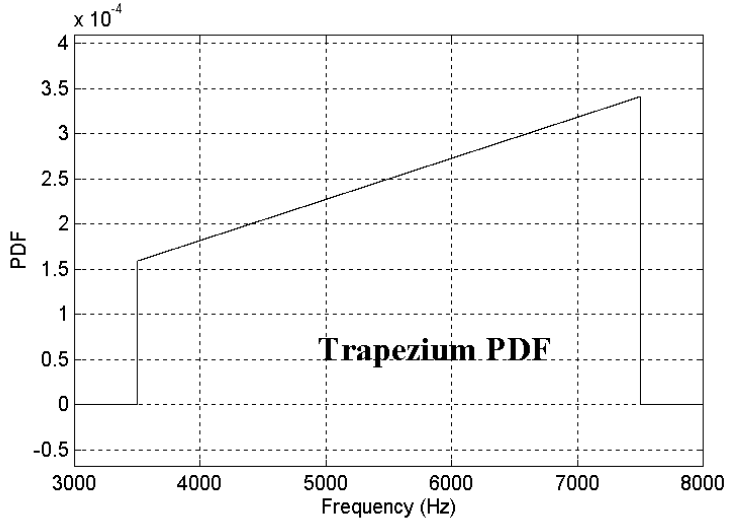


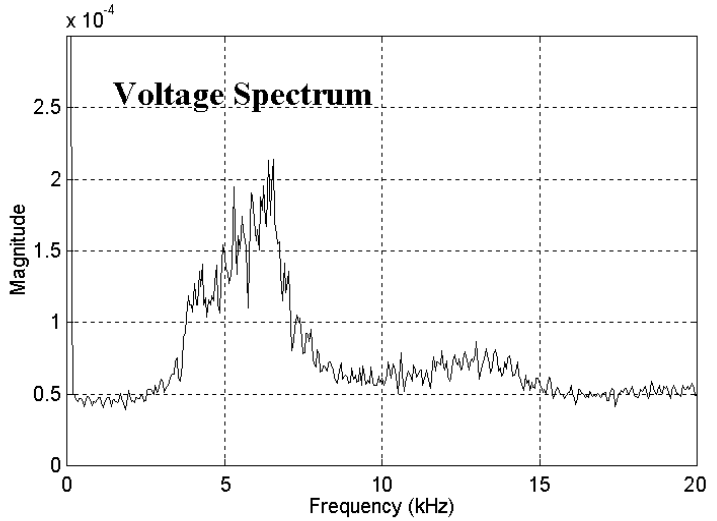
# PDF COMPARISON

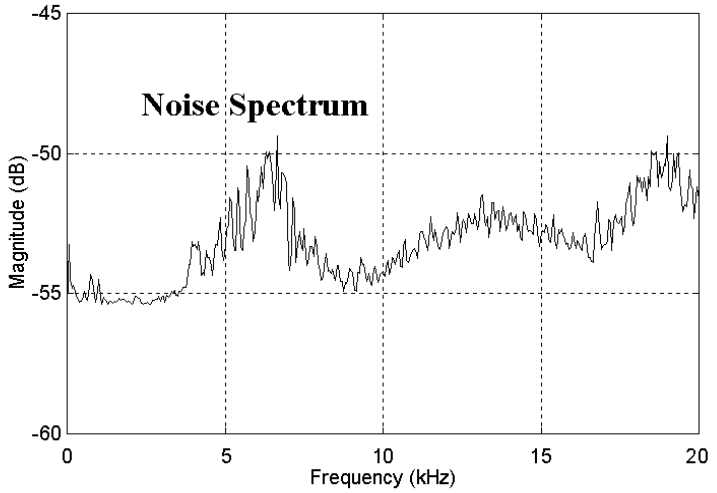
| PDF | peak increase of $V_{l\text{-}l}$ spectrum (%) | peak increase of the noise spectrum (dB) |
|---|---|---|
| **Uniform** | 24.89 | 2.218 |
| **Trapezium** | 23.15 | 2.257 |
| **Pink hyperbolic** | 45.19 | 4.552 |
| **Laplacian** | 30.73 | 2.943 |
| **Cauchy** | 11.15 | 3.203 |
| **Rayleigh** | 52.24 | 2.346 |
| **Maxwell** | 34.96 | 2.311 |



# PSEUDO-LINEAR RELATIONSHIP



# CONCLUSIONS

- Line voltages and noise are greatly effected by the PDFs
- Pseudo-linear relationship
- The PDF should be designed for optimal results