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DCL Channel Noise Characteristics:

A Survey of Measurements

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Research Report
No. EE 11

March 1994

Research Reports

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DLC CHANNEL NOISE CHARACTERISTICS :

A SURVEY OF MEASUREMENTS

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RESEARCH REPORT No. EE 11

DEPARTMENT OF ELECTRICAL ENGINEERING

UNIVERSITY OF CENTRAL QUEENSLAND

March 1994

ABSTRACT

Knowledge of the characteristics of electrical noise in the power distribution network's between 2kHz to 150kHz is essential for optimum DLC system design. The available literature is surveyed to identify noise characteristics of typical DLC channels. Reported measurements to date indicate that DLC noise predominantly originates from customer's loads and is a mix of two or more noise processes. It is typically nonstationary and impulsive in nature.

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1. INTRODUCTION

Many different Distribution Line Carrier (DLC) systems have been implemented over the last 20 years in an attempt to meet the demand for reliable data communications over the power Distribution Network (DN). Experience to date indicates that their performance is not yet acceptable. One reason for the slow progress is the poor propagation and noise characteristics of the typical DLC channel. Meanwhile research and development continues in an attempt to improve data transmission reliability as well as the data rate [14,18,31]. One of the focuses for research workers in this area is to determine typical DLC channel noise characteristics via field measurements. This information is necessary for the optimisation of communication system designs.

This report reviews available literature in an attempt to gain an understanding of the state of progress of such work. Specifically answers are sought to the following questions:

- What DLC channel noise characteristics have been measured, and how?
- What conclusions can be drawn about a typical DLC Channel's noise characteristics.

Most of the DLC literature originates in Europe and North America. No references to the characteristics of noise in Australian DN's could be located. Further more this report is restricted to DN noise characteristics. The other two sections of the power reticulation network, namely the Transmission and Customer Networks are not considered.

2. DN NOISE and MEASUREMENT TECHNIQUES

DLC channel noise refers to the stochastic noise signal observed at the input to a typical DLC receiver. A noise measurement made at any given receiver at any given time is therefore one particular example or realisation of the DLC channel noise process. Because of the particular stochastic characteristics of DLC channel noise any one measurement, even if it were made for all time, cannot alone be used to define the noise. Measurements must be made at a statistically significant number of receivers and DN's. Any quantitative conclusions that are drawn from such measurements must be presented as statistical quantities which will depend on the particular noise parameters measured. Qualitative conclusions must also recognise the stochastic nature of DLC channel noise and the inherent dangers of basing conclusions on very limited sample size.

It can be shown that the characteristics of DLC channel noise at a give receiver will be determined by the characteristics of the following [2,5]:

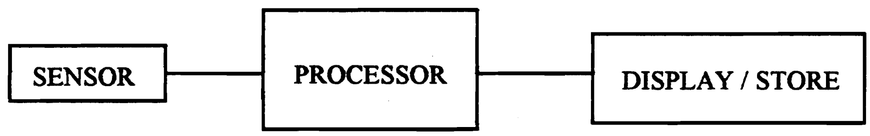
- Individual noise sources and their coupling to the DN.
- DN propagation paths from the coupled sources to the receiver coupling point.
- DLC receiver coupling-unit.

The receiver coupling-unit's characteristics are of special interest when interpreting DLC noise measurements since the coupling-unit is part of the DLC equipment and is built to a specified design which will partly[1] determine its characteristics. In addition the DN is a multi-conductor network and the coupling-unit design will dictate which conductors are to be coupled and how the individual coupled conductors' voltages and / or currents are combined and processed before connection to the receiver. Thus it is conceivable that the characteristics of the noise observed at each DN conductor at the point of coupling may be significantly different to the observed DLC channel noise. In this report we will distinguish between the noise which exists on the network and noise observed after the coupling-unit by using the term DN noise to refer to the noise before it is processed by the receiver coupling-unit. The same term will also be used when referring to general noise in the DN when it is not certain that the noise is observed at the output of a coupling-unit; ie., whether it is DLC noise. From DN

[1]The dynamic state of the DN coupling point impedance can also affect the characteristics [3,4].

noise measurements the noise characteristics at the input to a receiver's detector, that will most influence the performance of a DLC system, could be determined.

In analysing the performance of DLC communication systems, both spectral and time-domain noise characteristics need to be studied. While conventional communication system performance analysis assumes a stationary noise process whose statistics are Gaussian, this noise can be uniquely described by its power spectral density. If the spectrum is also flat the noise is referred to as Additive White Gaussian Noise which can be specified by its mean and variance. DLC channel noise processes are seldom Gaussian and include a large component of impulsive. Thus time-domain parameters, such as amplitude probability distribution (APD), average crossing rate (ACR), pulse width distribution (PWD), pulse interval distribution (PID), etc. [10,26,27], can have a significant bearing on how the noise effects system performance.



General Noise Measurement Instrumentation

FIGURE 1

Noise measurement instrumentation can typically be modelled by a functional block diagram as shown in Figure 1. Sensors are installed to obtain the noise signal for processing. Ideally the sensors should not distort the noise signal, affect the noise in the measured network or add any additional noise. They should also be capable of calibration so that actual network noise voltages and currents can be accurately determined. For DN noise measurements both indirect and direct sensing techniques could be used. For example electric and magnetic field sensors can be used to measure near field electromagnetic waves produced by conductor voltages and currents and thus indirectly obtain the primary quantities of measurement. Alternatively voltage and current probes can also be used for direct conductive measurements [33]. The field sensors are considered more convenient particularly for MV power lines whose conductors are at dangerous high voltage levels.

The noise signals obtained by the sensors will need to be processed to obtain the desired noise parameters. This will typically involve signal processing techniques such as filtering, analogue-to-digital conversion, spectral estimation, etc., to obtain the desired time and / or spectral parameters. When interpreting the resultant time and spectral measurements it is important to take into account the uncertainty principle of signal theory [16]. This principle teaches that if an accurate measurement is to be made at an instant in time then the measuring equipment must have a wide bandwidth and therefore cannot accurately define the frequency at which the measurement is made. Conversely accurate frequency measurements require a long period of time and therefore have poor time resolution. It should also be noted that, with the exception of Gaussian noise, signal processing such as filtering could change noise statistics [8,20].

The processed noise measurement is normally displayed and stored for further analysis. Two and three-dimensional displays can be used to improve visualisation of the noise process. For example spectra can be displayed as two-dimensional graphs or as three-dimensional frequency-time graphs. Statistical results are typically displayed in the form of probability distributions.

Some of the instrumentation used for DN noise measurement as reported in the literature is summarised in Table 2.1. It is observed that all reported DN noise measurements are spectral measurements and that no statistical results are reported. The latter technique has been used in an attempt to describe Customer Network noise [10] and radio impulsive noise produced by very high voltage power transmission lines [26]. These same techniques could be use for DN noise measurements.

	INVESTIGATORS YEAR REFERENCE	SENSOR	PROCESSOR	DISPLAY	Via COUP. - UNIT	FREQ. RANGE kHz
1	Smith, 1972, [28]	Cond.[2]	Receiver	Power Spectral Density	No	10 - 10^5
2	Owen et.al., 1980, [22]	E and H	Scanning Analyser	3D freq.-time	No	3 - 300
3	Spotts, 1982, [29]	Cond.	FFT Analyser	2D freq.	Yes	3 - 50
4	Vines et. al., 1984, [34]	Cond.	FFT Analyser	2D freq.	No	5 - 100
5	SRI International, 1985, [33]	E and H and Cond.	Scanning and FFT Analysers	2D freq.and 3D freq.-time	Some	10^{-2} - 10^6
6	Chan & Donaldson, 1989, [10]	Cond.	Computer	Probability Distributions	No	30-40, 70-80

Summary of DN Noise Measurement methods

TABLE 2.1

3 REPORTED FINDINGS ON NOISE MEASUREMENTS

This section reviews findings of published DN noise measurement projects. The majority of the literature devoted to DLC noise originates in North America. Some European noise measurements are reported briefly in the general DLC literature.

[2] Cond. refers to conductive sensor; E electric field sensor; H magnetic field sensor

European and North American DN structures are significantly different. In North American, typically a large number of relatively small, single-phase Distribution Transformers (DT) are connected across three-phase MV feeders at various points. Each DT secondary feeds only a small number of customers. In Europe, fewer, but larger three-phase DT's are employed, feeding large LV networks. These differences have resulted in different network architectures and DLC systems being employed in European and North America [5]. Since the DT can act as an isolator at high signal frequencies MV and LV networks are often viewed as DN sub-networks particularly in European network architectures [5]. It is therefore appropriate to consider North American and European MV and LV noise measurement projects separately.

3.1 North American MV Networks

Six projects which attempt to measure DN noise measurement have been reported. Rockwell International as part of a programme to develop DLC systems in the 1970's conducted a series of noise measurements. They concluded that DN noise was mostly impulsive and bursty in nature dominated by 60Hz harmonics [9]. No Quantitative measurement results were given.

General Electric (GE) also conducted tests in the 1970's and 80's and concurred with Rockwell's findings [32]. In addition they showed that a large proportion of harmonic noise was not in the form of zero sequence voltages. They were able to demonstrate that the noise at the input to a DLC receiver operating in the 5 to 10kHz band could be reduced by 15 to 20dB, by using mode 3, or zero sequence, coupling where all DN conductors are coupled with respect to earth. Large noise bursts were observed on DN lines with levels 20 to 30dB above normal noise. The mean time between occurrences was observed to be 2 minutes at one substation. The researchers attributed the cause of these large noise bursts to step changes such as power plant switching and motor starting.

In 1980 Owen et.al. [22] measured the spectrum of electric fields close to open-wire transmission lines, on a 14.4kV feeder of the Connecticut Light and Power company and a 13.8kV feeder owned by the Potomac Electric Company. Both feeders were known to have unfiltered synchronously switched power converter loads. Virtually all observed noise was impulsive and synchronous with the power frequency. While the power converters were identified as the dominant noise sources significant levels of impulsive noise still remained when the converters were not operating. The noise spectrum was observed to be in the frequency range 3 to 300kHz , and contained peaks and troughs that varied with measurement location and network topology (eg., switching capacitor banks in and out). The distance from the measurement site to the converter noise source was found to bear no direct relationship to the level of the measured noise. For example it was reported that at one relatively close location no converter noise was observed while at a more distant site it was found to be at high levels. It is not clear whether these measurements were obtained simultaneously. The noise was found not to be present on feeders separated from the converter by sub-station transformers. The highest noise levels were observed to have their major spectral components below 75kHz. The tests used primarily radiated measurements. There were no reports on conducted measurements which are required for quantitative studies of DLC channel noise.

Spotts [29] in 1982 measured the noise voltage spectrum on six 23kV feeders at four substations in North Carolina in the frequency range 3 to 50kHz. Specifically he was interested in obtaining four sets of noise related parameters:

1. Noise voltage spectrum
2. Harmonic-to-background noise ratio
3. Peak-to-average noise ratio
4. Bandwidth of an harmonic spike

Special consideration was given to the 5 to 15kHz band in which most North American DLC systems operate. The test feeder was connected to a Nicolet 660B digital spectrum analyser via a standard Westinghouse DLC coupling-unit with a

1.5kHz highpass filter characteristic. A 10 to 1 oscilloscope probe was used to further reduce the voltage at the analyser input. During the experiment the noise was observed to be nonstationary and all measured noise voltage spectrum contained peaks and troughs. The noise level and the pattern of peaks and troughs were observed to be different for each feeder. In general the noise level was observed to decrease with frequency. From the test results Spotts concluded that DLC noise was primarily a combination of white noise and 60Hz harmonics, although the reported results do not appear to support this conclusion. In the noise spectrum reported by the author it was observed that, although 60Hz harmonics dominate, particularly below 15kHz, they rise out of a relatively smooth noise floor whose level clearly varies with frequency and therefore the noise cannot be defined as white except over very narrow bandwidths such as the gap between adjacent harmonics. Background noise is a more accurate description of this noise and this term will be used in this report when referring to Spott's "white noise"

Spotts reported his noise measurements in the form of spectrum. The data is in the form of spectrum analyser displays of the average voltage noise spectrum recorded on each of the six feeders [29]. The Fast Fourier Transform magnitudes of 100 sample blocks were averaged. The time interval between samples was not specified. In order to gain a better appreciation of the statistical nature of the noise measurements some of the results obtained by Spotts have been used in the construction of the charts in Figures 3.1, 3.2 and 3.3. Figure 3.1 shows the range of all measurements at 8 discrete frequencies while Figure 3.2 gives the range on each feeder. Figure 3.3 is a plot of the noise measurements on each feeder recorded at eight discrete frequencies between 5 and 50 kHz. It should be noted that because of the non-stationary nature of the noise and the unknown averaging period it cannot be assumed that these measurements are representative of the feeders' noise levels. They do however show the wide range of noise levels, the difference of noise levels between feeders and the tendency for noise levels to be lower on all feeders at higher frequencies .

From his average voltage noise spectral measurements Spotts also attempted to find the approximate harmonic-to-background noise ratio on all six feeders at four discrete frequencies between 5 and 14kHz. This was not always possible for some measurements because the background noise was found to be below the dynamic range of the analyser and the ratio could not always be determined. In addition, this ratio was also found to vary with time because of the non-stationary nature of the noise. Spotts gave as an example two measurements made 5 minutes apart on the same feeder where the background noise varied by 15dB although the harmonic noise remained constant. This variation was not however observed on other feeders. Spott's result, which is summarised in Figure 3.4, established its range of the ratio's variation with frequency and between feeders. These results must be accepted with some reservation since Cummins et.al. [11] when measuring power line noise affecting HF-radio communications have shown that the averaging process tends to reduce the level of background noise relative to the harmonics.

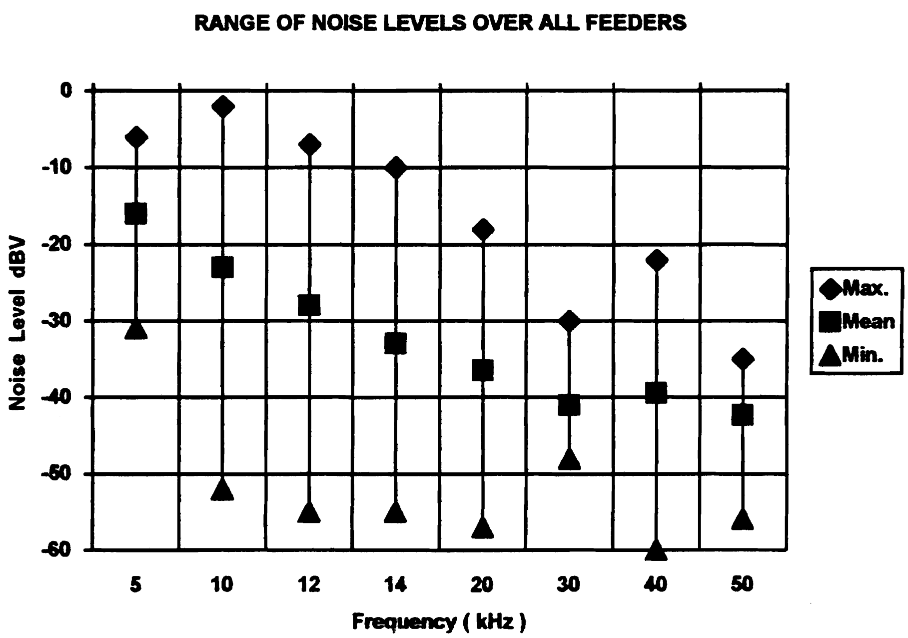


FIGURE 3.1

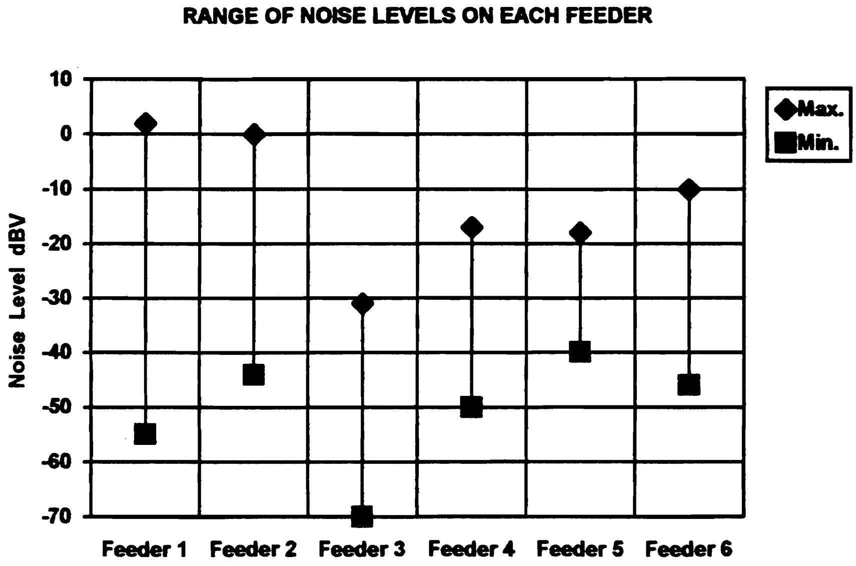


FIGURE 3.2

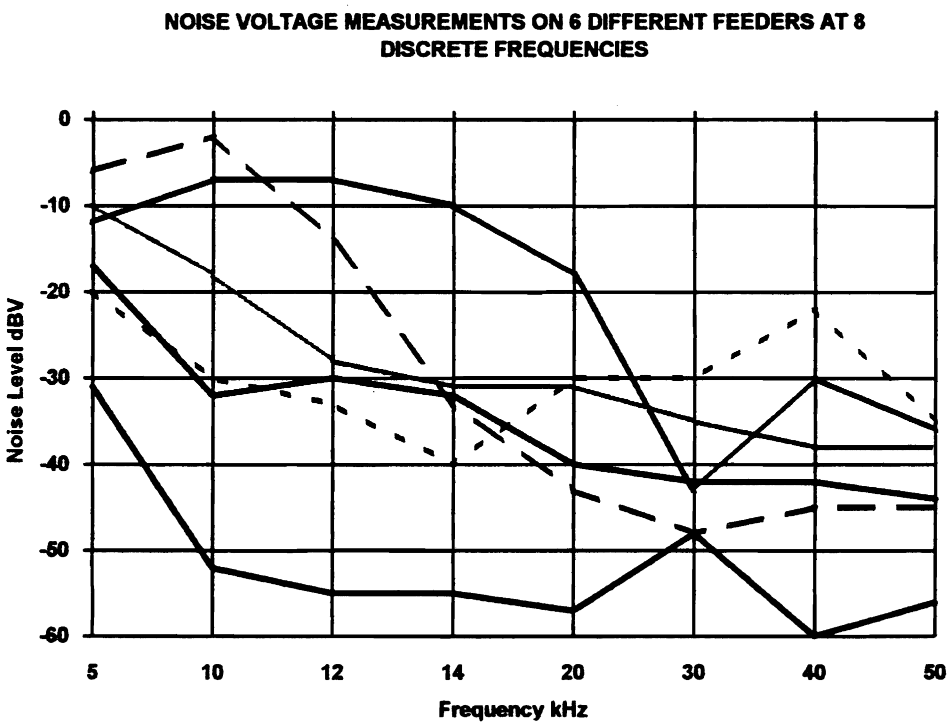


FIGURE 3.3

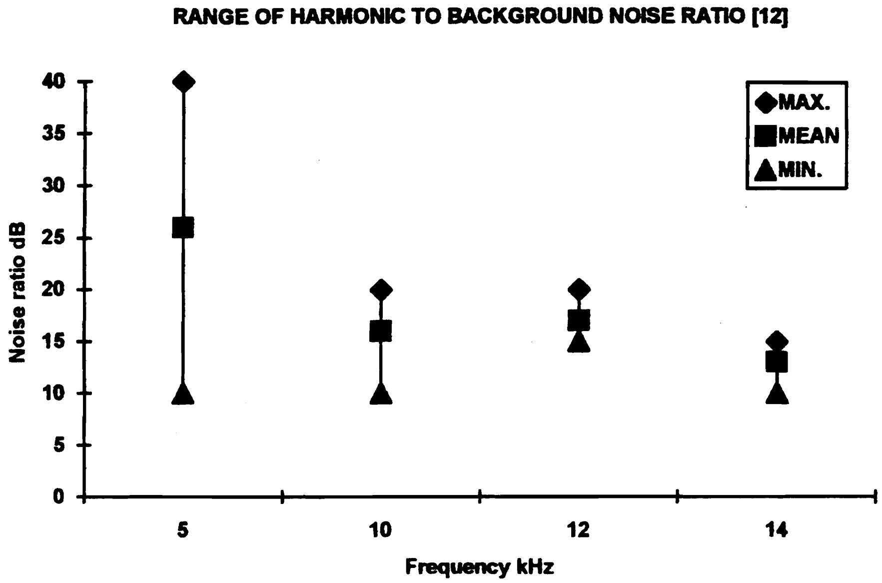


FIGURE 3.4

Spotts [29] also considered the peak-to-average noise ratio at four discrete frequencies between 5 and 14 kHz on all six feeders. For each frequency the average of the FFT magnitudes of 100 sample blocks was used with the peak value being the maximum magnitude recorded during the 100 samples. Again the sampling period was not specified. It was found that this ratio varied erratically and its relationship to frequency or a particular feeder was not apparent. The mean of the ratio for all frequencies and feeders was reported as 8.79dB. The peak-to-average ratio of the harmonic and background noise were determined separately at the four discrete frequencies. It was found that the ratio for background noise appeared to vary little being about 10dB but was extremely unpredictable for the harmonic noise and could vary between 0 and 15dB for adjacent harmonics on the same feeder.

Spotts estimated from expanded spectrum measurements the bandwidth of the 208th harmonic spike (12.48kHz) to be 3Hz. He suggested that the cause of the bandwidth was jitter of synchronously switched loads and variations in the power frequency over the 7 minute measurement period.

The most extensive DN noise measurement project on North American MV networks was conducted by SRI International for the Electric Power Research Institute (EPRI). The results were reported in 1985 [33]. In the project both radiated and conducted noise measurements were made over a three year period on 100 feeders at 10 power utilities across the US. Measurements were made at frequencies between 10Hz and 1GHz although primary interest was focused on the 1 to 15kHz DLC band. Similar types of noise were observed at all utilities although noise amplitudes were observed to vary at different locations. These variations however could not in general be attributed to the location alone; ie. urban, rural etc.

Measurements were also made at the DLC system side of coupling units at substations and remote terminals. Both capacitor and distribution transformer (DT) coupling [3] was used. The measurements are given as voltage noise spectra between 0 and 20kHz.

During the tests it was observed that the dominant noise in the DLC band was always synchronous impulsive noise produced by customer loads which appeared in the frequency domain as harmonic noise. It was also found that the harmonic levels were generally higher at locations remote from the substation. In the view of the researchers, the harmonic amplitudes at some locations were too high for effective DLC system operation. Further more it was observed that noise levels tended to decrease with frequency, especially for measurements using the DT coupling. This is hardly surprising in view of the frequency characteristics of the DT coupling-unit. The noise spectrum was observed to contain peaks, troughs and noise bands whose position and amplitude depended on the test location and time but typically occurred in a band from 5kHz to 18kHz. Sudden changes in noise levels were commonly observed associated with customers' loads being switched on or off.

The researchers occasionally observed single impulses with amplitudes up to 30dB above harmonic amplitudes. The spectral shape, amplitude and bandwidth of these impulses varied greatly between pulses.

It was an initial aim of the EPRI project to obtain a statistical description of DN noise. Because of the nonstationary nature of the measured noise and its erratic behaviour, attempts to describe the noise levels with common statistical measures proved very difficult and no statistical description was produced.

During the SRI project gap noise was commonly observed. Gap noise refers to the noise produced by discharges between charged metal line components as described in [27]. The general temporal and spectral structure of the observed gap noise was similar for all MV lines regardless of voltage however the number of gap noise sources increased significantly with increased voltage. The observed gap noise had distinctive time and frequency domain characteristics. It consisted of groups of impulses spaced at intervals equal to half the power voltage period. The typical spectrum covered a very wide bandwidth (30kHz to > 500MHz) and contained numerous valleys and peaks which the researches attributed to the resonant properties of the radiating mechanisms. Sources of gap noise were often intermittent and influenced by climate and pole vibration. The SRI report [33] contains only one noise spectrum measured at a DLC receiver located close to a gap noise source in the 2 to 100kHz band. A synchronously switched load was also located in the area. Power harmonics dominated at frequencies below 30kHz with levels decreasing with frequency while gap noise of relatively constant level occupied the 30 to 100kHz band. The gap noise level was approximately 40dB lower than the harmonic noise level measured at 10kHz.

An interesting demonstration of the presence of interference signals on the DN was also reported. DLC signals were sometimes observed from systems operating on other feeders connected to the same substation and occasionally feeders from other substations. In addition signals from unauthorised customer communication systems using the DN as a bearer were also observed.

The latest reference on North American MV network noise experiments that could be located is by Wang and Trussell [35] 1988, who showed a time-domain sample of DLC noise recorded on one phase at a substation. It was observed that synchronous impulsive noise is clearly dominant and consists of two major impulses per power cycle interspersed with smaller impulses. This was attributed to coupling from the other phases of the three phase power system.

North American MV network noise measurement attempts are summarised in Table 3.1.

	INVESTIGATORS YEAR REFERENCE	NETWORK DETAILS	FREQUENCY RANGE kHz	DOMINANT NOISE	COMMENTS
1	Rockwell, 1970's,[9]	NG[3]	MI[4] 5-15	Harmonic	Impulsive and bursty
2	General Electric, 1970's, [32]	NG	MI 5-15	Harmonic	Large transients 30dB above harmonics; Mode 3 coupling best
3	Owen et.al., 1980, [22]	14.4 & 13.8kV OH[5]	3-300	Harmonic	Large unfiltered converter loads; dominant noise was below 75kHz
4	Spotts, 1982, [29]	Six 23kV, OH	3-50	Harmonic	Large range of noise levels
5	Wang, Trussell, [35]	MV	1 - 20	Harmonic	
6	SRI International, 1985, [33]	Large number, mainly OH	10^{-2} - 10^{6} MI 5-15	Harmonic < 30kHz, Gap noise >30kHz	Large transients 30dB above noise levels and other noise types also observed

Summary of North American MV Network Noise Measurements

TABLE 3.1

[3] NG indicates that information was not given.
[4] MI is an abrevation for "main interest".
[5] OH indicates over head line construction.

3.2 North American LV Networks

A total of four references have been located on noise measurements on North American LV networks. The first was conducted by Rockwell International in the 1970's. The major conclusions from the experiment was that noise measured within a LV network generally originated from loads within that network and not other LV networks [9].

Smith [28] in 1972 conducted experiments to establish power line noise power spectral density measurements using a 50Ω receiver connected between neutral and ground. The limited samples were obtained at six US customers' premises in the frequency band 10kHz to 100MHz. Smith found that the noise power spectral density was not flat but decreased with frequency with a slope of approximately -29dB per decade. He also found that the noise level at urban locations were up to 30dB higher than those at rural sites.

Vines et.al. [34] in 1984 measured the 5 to 100kHz noise spectrum of typical residential electrical loads under control conditions at the Carolina Power and Light Company. Measurements were made at five typical residences. They identified the following noise types in the LV network:

- noise which was synchronous with the power frequency. This appeared to be produced by switching devices such as SCR's and switch-mode power supplies.
- noise with a smooth spectrum, that was generated by universal motors which behave as high frequency current sources of random impulsive noise. This noise was attributed to the motor's commutation process.
- single event impulsive noise, which was caused by lightning and network switching.
- non synchronous periodic noise, which typically was caused by TV receivers.

The loads causing the most residential noise in the measured bandwidth were found to be:

- light dimmers, up to 40dB above normal noise at 10kHz for 400 W of lighting.
- universal and dc motors, with up to 30dB increase in noise for large motors.
- TV receivers with horizontal line frequency harmonics up to 40dB above background noise.

It was observed that induction motors and fluorescent lights produced little noise.

Vines et.al. concluded that the type and level of the noise measured at a residence was determined mostly by the appliances connected at that residence and to a lesser extent by the loads connected at a neighbour's residence in the same LV network. They observed that the influence of noise entering the LV network via the DT was insignificant. Interestedly, comparison of simultaneous spectral measurements of noise generated at a residence to that measured at a neighbour's residence with no loads connected revealed significant differences in level and shape.

Chan and Donaldson [10] in 1989 measured power line noise in industrial and residential buildings in Canada in the 30 to 40kHz and 70 to 80kHz bands. They attempted to estimate the probability distributions of the amplitude, width and interarrival times of noise impulses and their effect on short range Customer Network communication applications. Chan and Donaldson's measurements showed that most noise sources contained a significant impulse noise component. They concluded that typical Customer Network noise could be viewed as large impulses rising from a low background noise. In addition the relative strength of the impulses was found to depend on the electrical loads connected and their location relative to the observation point. Impulse frequency was typically 120Hz and synchronous with the positive and negative half-cycles of the power voltage. Some loads only contributed background or impulsive noise while others produced both.

Standler [30] in 1989 reported his experiment of using a digital oscilloscope to measure transients on the 120V power circuit at his residence over a period of two months in the summer of 1986. His purpose was to investigate overvoltage protection requirements. The oscilloscope was triggered when transients having a positive slope and with frequency components greater than 50kHz reached a preset voltage level. Measurements were made at the end of a length of cable 18 m from the power service entry. The events that triggered the oscilloscope were classified as follows:

- high frequency noise bursts attributed to reactive load switching.
- a sudden fall in the power voltage when low impedance loads were switched on.
- transients during local thunderstorms produced by lightning strikes near the open-wire distribution lines.

Standler observed that the average number of event occurring per hour was low, typically less than 1.6. He estimated that about 60 percent of all observed events originated within the residence. In addition, Standler observed that the transients produced by nearby lightning strikes appeared as bursts of high frequency noise which typically lasted for 30μs. He suggested that the cause of this noise was corona discharge [27] from the open-wire lines in the large electric fields associated with the lightning. About 3 percent of all observed transients were high frequency (1.8MHz) 24μs bursts. Although it was clear that these bursts were not associated with thunderstorms their source could not be determined.

Standler also measured the transient voltage across typical domestic loads as they were switched on. He found that low impedance loads such as a 150W tungsten lamp and a stove caused the voltage to suddenly collapse from 171 V to 100 V with an initial slope of 6.8 kV/μs and then slowly recover in approximately 50μs. The maximum slope of voltage collapse was found to be 17.2kV/μs as observed for a Vacuum cleaner with a 720 VA motor. Switching inductive loads such as devices with electric motors were found to produced noise bursts of about 150 μs duration.

Although Standler's paper does not provide any spectrum of the transients it is likely that some of their energy will be found in the frequency bands occupied by DN and Customer Network communication systems. Research currently being conducted at the University of Central Queensland plans to investigate the effects of these transients.

Table 3.2 gives a summary of North American LV network noise measurements.

3.3 European MV Networks

Only four references could be found that include reports of European MV network noise.

In 1981 Realp et.al. [23] made noise measurements on four MV cable networks in Spain as part of a project to investigate DN communications. They found that at frequencies above 50kHz noise levels never exceeded -68dBV using a 120Hz bandwidth filter.

	INVESTIGATOR YEAR REFERENCE	**NETWORK DETAILS**	**FREQUENCY RANGE kHz**	**DOMINANT NOISE**	**COMMENTS**
1	Smith, 1972, [28]	Six Customers Premises	$10 - 10^5$	NG[6]	Noise was coloured with slope ≈ -29dB/decade
2	Vines et. al., 1984, [34]	Five residences and typical appliance loads	5-100	Harmonic	Nonsynchronous impulsive and periodic noise also observed
3	Chan & Donaldson, 1989, [10]	Residential & industrial buildings	30-40, 70-80	Harmonic	Statistical time domain measurements
4	Standler, 1989, [30]	Residence	> 50	Transients	Only time domain transients were measured

Summary of North American LV Network Noise Measurements

TABLE 3.2

[6] NG indicates that information was not given.

Michelis et.al. [12], 1985, observed that the noise level measured on a 20kV MV cable network in Italy varied significantly with time. Variations up to 15dB for a 30 min. and 25dB for a 100ms integration period were recorded. Noise bursts whose total duration occupies less than 2% of the observation period were also present. Quantitative measurement details were not supplied.

Hoeffelmann et.al. [17] ,1987, measured noise in different cable and mixed MV networks in the bandwidth 1 to 20kHz. In general harmonic noise was found to dominate up to about 10kHz with noise levels measured as high as +10dBV at low frequencies. The noise level was observed to decrease with frequency. The remainder of the spectrum contained a relatively flat background noise with some peaks, attributed to industrial origin, whose level seldom exceeded -30dBV at the output of a 30Hz bandpass filter. The background noise ranged from -70dBV to -50dBV.

McMillan et.al. [19], 1987, reported the rare observation of broadcast radio signals on DN lines. The signals at 16 and 19kHz were measured on a 11kV cable network with a small section of overhead line at its end.

A summary of European MV noise measurements are given in Table 3.3.

3.4 European LV Networks

Again only a small number of reported noise measurements could be located.

Refsum and Fox [24], 1982, measured noise from 100Hz to 10kHz on a LV network at The Queen's University of Belfast. The envelope of the power harmonics which dominated the voltage spectrum had a slope of -35dB per decade.

Hagmann [15] in 1989 reported typical noise voltage spectra to 200kHz measured on an LV network in Switzerland. He reported that harmonic noise dominated at low frequencies. The noise level was observed to decrease with frequency to a relatively flat background noise at about 20kHz. The background noise level was approximately 70dB below the maximum harmonic noise. Within the flat background noise numerous narrow-band peaks appeared above the background noise level by as much as 40dBV. Some of the peaks were observed to be nonstationary in the short term. The author attributed this to pulsed interference. In the 120kHz bandwidth spectra given in Hagmann's paper there were 19 stationary narrow-band peaks. He attributed the stationary peaks to power harmonics and tone interferers. The pulsed interference appeared to result from randomly spaced events in time with an average rate of 0.5 per second for the very limited example given in the paper.

	INVESTIGATORS YEAR REFERENCE LOCATION	NETWORK DETAILS	FREQUENCY RANGE kHz	DOMINANT NOISE	COMMENTS
1	Realp et.al., 1981, [23], Spain	MV cable	40-320	NG[7]	Noise levels < -68dBV
2	Michelis et.al., 1985, [12], Italy	MV cable	NG	NG	Noise bursts observed
3	Hoeffelmann et.al., 1987, [17], NG	Mixed MV	1-20	Harmonic < 10kHz	Above 10kHz background noise with narrow band peaks
4	Refsum & Fox, 1982, [24], UK	LV	0.1-10	Harmonic	slope - 35dB/decade
5	ASEA Brown Boveri, 1989, [25],Switzerland	LV	0-125	Harmonic <20kHz	Above 20kHz background noise with narrowband peaks 60dB higher
6	Hagmann, 1989, [15], Switzerland	LV	0-200	Harmonic < 20kHz	Above 20kHz background noise with narrow band peaks (40dB higher) some impulsive

Summary of European DN Noise Measurements

TABLE 3.3

[7] NG indicates that information was not given.

ASEA Brown Boveri during the course of developing their DLC system, ROBCOM, conducted noise measurements on LV networks. They concluded that DLC noise is not dominated by harmonic noise in the frequency band 20kHz to 150kHz [25]. A sample noise spectrum in this band showed a relatively flat background noise with some narrow band peaks. The dominant peaks were at some harmonics of the TV horizontal line frequency. They were observed to rise as much as 60 dB above the background noise.

European DN noise measurements are summarised in Table 3.3.

4 OBSERVATIONS and CONCLUSIONS FROM REPORTED FINDINGS

An important task when attempting to describe and measure channel noise is to determine which noise parameters should be used. Clearly the chosen parameters should relate to the effect of the noise on a communication system's performance. It is the noise characteristics at the input to a communication receiver's detector that will most influence this performance. Stationary Gaussian noise for example can be uniquely described for this purpose by its power spectral density. With impulsive noise however the time domain parameters of the impulses can have a significant bearing on system performance. Stationary impulse noise can be described by standard statistical forms such as amplitude probability distribution (APD), average crossing rate (ACR), pulse width distribution (PWD), pulse interval distribution (PID), etc. [10,26,27]. As has been shown in this report DLC channel noise is typically a combination of different noise processes and is impulsive and nonstationary. Its description is not a straightforward matter.

The following general observations are made after a study of the twenty or so reported noise measurement projects:

4.1 Observation 1.

All reported DLC noise studies are based on spectrum measurements and do not include a statistical description of the noise. Defending their omission of statistical descriptions when reporting their study of DN noise, SRI International investigators [33] claimed that, since the noise is dominantly nonstationary, varying from location to location and abruptly with time, conventional statistical measures are not adequate descriptions.

4.2 Observation 2.

While the number of reported noise measurement projects was small some qualitative observations could be made about the characteristics of DN noise:

- DN noise is typically a mix of two or more noise processes each with independent properties.
- DN noise is not white but has a varied spectral structure typically containing peaks and troughs.
- The main sources of DN noise are customers' loads. Loads containing switching devices are the dominant source of synchronous impulsive noise. Loads such as universal motors produce a random impulsive noise with a smooth spectrum. TV receivers are a typical source of narrow band non synchronous periodic noise. Probably the majority of noise bursts, at least in LV networks, originate at the customer.
- Most of the noise within an LV network originates within that network probably partly due to the isolation effect of the distribution transformer [4].
- Gap noise is sometimes observed at frequencies above 30kHz. Its source is power line plant.

- DN noise varies significantly from location to location and with time having a variety of temporal and spectral structures. It is dominantly nonstationary over its entire frequency range.
- At frequencies below 20kHz synchronous impulsive (harmonic) noise dominates. Harmonic noise levels significantly decrease with increasing frequency.
- For frequencies above 20kHz low level background noise containing narrowband peaks is typically observed.
- Impulsive noise is observed at all DLC frequencies and large noise bursts or transients are common.
- Noise bursts, due to lightning strikes and DN plant switching, and gap noise, which is probably confined to MV networks, are the major noise sources of non-customer origin.

4.3 Conclusions

A clear distinction should be made between DLC channel noise and DN noise as they are defined in this report. DLC channel noise is the noise observed at the input to the typical DLC receiver while DN noise refers to the noise voltages and currents observed on DN conductors. The characteristics of DLC channel noise may vary depending on the coupling employed and can be determined from DN noise characteristics given coupling-unit specifications and a knowledge of the dynamic state of the DN coupling impedance. Determining the characteristics of DN noise should therefore be the aim of measurements.

Because of the demonstrated nonstationary nature of DN noise, the DN's multi-conductor transmission lines, and the possible effects of instrumentation on noise signals it is essential, for their effective use, that the following information accompany any DN noise measurements projects:

- a detailed description of the instrumentation used including its connection to the DN

- the location, conditions and time of the measurements.

These details were not documented in most of the reported measurements in the literature.

While an attempt has been made in this report to derive some qualitative description of DN noise, a quantitative statistical description of the noise is however required so that optimal communication systems, including coupling-units, and network architectures can be designed. Further work will also be required to quantify a useful set of statistical properties for DN noise and its components.

5. REFERENCES

1 J. Barnes, K. Kwong, " DLC Channel Propagation Characteristics: a Survey of Measurements", Research Report No. EE9, Dept. Elect. Engr., University of Central Queensland.

2. J.Barnes, K. Kwong, "Distribution Network Noise Modelling", Research Report, Dept. Elect. Engr., University of Central Queensland, (to be Published).

3. J.Barnes, K. Kwong, "A New, General Deterministic DLC Coupling Model", Research Report, Dept. Elect. Engr., University of Central Queensland, (to be Published).

4. J. Barnes, K. Kwong, " General Analytical Study of DLC Coupling ", Research Report, Dept. Elect. Engr., University of Central Queensland, (to be published)

5. J.Barnes, K. Kwong, "Distribution Network Communications: A Study of Existing Systems and Network Architectures", Research Report, Dept. Elect. Engr., University of Central Queensland, (to be Published).

6. J.Barnes, K. Kwong, "Distribution Network Propagation Simulator Analyser: Specification and Implementation Options", Research Report, Dept. Elect. Engr., University of Central Queensland, (to be Published).

7. J.Barnes, K. Kwong, "A New Multi-Path Distribution Network Propagation Model ", Research Report, Dept. Elect. Engr., University of Central Queensland, (to be Published).

8. W. Bennett, " Methods of Solving Noise Problems ", Proc. IRE, Vol. 44, May 1956.

9. G. Bowling, " The Power Distribution System as a Communication Medium ", IEEE Summer Power Meeting, 1979.

10. M. Chan and R. Donaldson, " Amplitude, Width, and Interarrival Distributions for Noise Impulses on Intrabuilding Power Line Communication Networks ", IEEE Trans. on Electromagnetic Compatibility, Vol. 31, No. 3, August 1989.

11. E. Cummins, S. Jauregui, W. Vincent, "Time-and Frequency-Domain Characteristics of Man-Made Radio Noise Affecting HF-Communications Sites", IEEE Trans. on Electromagnetic Compatibility, Vol. EMC-21, No. 3, August 1979.

12. F. De Michelis, C. Mirra, L. Mastrobuoni, G. Scozzari, " Signal Transmission Over Electric Power Distribution Network ", CIRED 1985.

13. W. De Wilde, D. Van Wassenhove, " Upwards to a Reliable Bi-directional Communication Link on the LV Power Supply for Utility Services: Field Tests in Belgium ", IEE International Conference on Metering Apparatus and Tariffs for Electricity Supply, 1990.

14. K. Dostert, " Frequency-Hopping Spread-Spectrum Modulation for Digital Communications Over Electrical Power Lines ", IEEE Journal on Selected Areas in Communications. Vol. 8, No. 4, May 1990.

15. W. Hagmann, " A Spread Spectrum Communication System for Load Management and Distribution Automation ", IEEE Trans. on Power Delivery, Vol. 4, No. 1, January 1989.

16. R. Harris, T. Ledwidge, " Introduction to Noise Analysis ", Applied Physics Series, Pion Limited, 1974.

17. J. Hoeffelmann, P. Sommereyns, A. Dedeurwaerdere, A. Nicolas, " Use of the MV Network for Remote Indication of Fault Current Detectors ", CIRED 1987.

18. M. King, J. Adame, T. Schaub, G. Rossi, F. Ziglioli, " Experimental Systems for Tele-Reading Over the Low Voltage Network", IEE International Conference on Metering Apparatus and Tariffs for Electricity Supply, 1990.

19. R. McMillan, R. Formby, R. Wilson, " The Development of Urban Feeder Automation in the United Kingdom ", CIRED 1987.

20. D. Middleton, " An Introduction to Stochastic Communication Theory ", McGraw-Hill, 1960.

21. P. Moose, J. O'Dwyer, " A Model for Impulsive Power-Line Radio Disturbance Due to Gap-Type Discharges ", IEEE Trans. on Electromagnetic Compatibility, Vol. EMC-28, No. 4, Nov. 1986.

22. R. Owen, W. Vincent, W. Blair, " Measurement of Impulsive Noise on Electric Distribution Systems", IEEE Trans. on Power Apparatus and Systems, Vol. PAS-99, No. 66, Nov./Dec., 1980.

23. E. Realp, M. Serra, J. Zubeldia, " Data Acquisition in a Distribution System Using the MV Underground Network as the Transmission Path ", CIRED 1981.

24. A. Refsun, B. Fox, " Comparison of Two Mains Signalling Methods for Load Control Within a Consumer's Network ", IEE International Conference on Metering Apparatus and Tariffs for Electricity Supply, 1982.

25. " ROBCOM : An Optimum Communications Concept for Electric Distribution Networks ", ABB Infocm AG, Dept. ENFR, 5300 Turgi, January 1989.

26. A. Sheikh, J. Parsons, " Statistics of Electromagnetic Noise Due to High-Voltage Power Lines ", IEEE Trans. on Electromagnetic Compatibility, Vol. EMC-23, No. 4, Nov. 1981.

27. E. Skomal, " Man-made Radio Noise ", Van Nostrand Reinhold, 1979.

28. A. Smith, " Power Line Noise Survey ", IEEE Trans. on Electromagnetic Compatibility, Feb. 1972.

29. T. Spotts, " The Measurement and Analysis of High frequency Noise on Electric Distribution Systems ", Master Thesis, North Carolina State University, Dept. Elect. Engr., 1982.

30. R. Standler, " Transients on the Mains in a Residential Environment ", IEEE Trans. on Electromagnetic Compatibility, Vol. 31, No. 2, May 1989.

31. J. Suh, M. Hardy, J. O'Neal, K. Shuey, L. Gale, " Measurements of Communication Signal Propagation on Three Phase Power Distribution Lines ", IEEE Trans.on Power Delivery, Vol. 6, No. 3, July 1991.

32. J. Tengdin, " Distribution Line Carrier Communications- an Historical Perspective ", IEEE Trans. Power Delivery, Vol. PWRD-2, No.2, April 1987.

33. W. Vincent, " Harmonic and Electrical Noise in Distribution Systems-Volume1: Measurements and analysis ", EPRI EL/EM-4290, Research Project 2017-1, Final Report, Oct.1985.

34. R. Vines, H. Trussell, L. Gale, J. O'Neal, " Noise on Residential Power Distribution Circuits ", IEEE Trans. on Electromagnetic Compatibility, Vol. EMC-26, No. 4, Feb. 1984.

35. J. Wang, H. Trussell, " Adaptive Harmonic Noise Cancellation with an Application to Distribution Power Line Communications ", IEEE Trans. on Communications, Vol. 36, No. 7, July 1988.

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