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**Title:**

Evaluation of TTY Solutions

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**Source:**

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**Abstract:**

The Lucent TTY solution, [1], along with solutions from Nokia, vocoder bypass [3] and tone [5], and Ericsson, [6], were tested against the requirements [8]. Exhaustive testing demonstrates that the Lucent TTY solution meets or exceeds all of the requirements.

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**Recommendation:**

Adopt Lucent's TTY solution presented in TR45.3.5/99.08.16.20 for TIA/EIA 136-410 (IS-641-A).

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## 1. Introduction

In the August meeting of TR45.3.5, it was agreed upon that each company with a TTY solution would exchange PC executables and test each others solutions in side-by-side tests. Two solutions were submitted from Nokia, one from Ericsson, and one from Lucent.

Ericsson's solution contained a combination of SUN executables and Matlab m-files, neither of which were in the agreed upon PC executable format. Lucent did not possess the resources to run their simulation, hence Lucent did not test their solution. However, according to the file `readme.txt` attached to the email sent by Ericsson [7], their simulation does not handle 50 baud, interactive character mode, nor interoperability, therefore these table entries for the Ericsson candidate are marked as failures in the tables below.

A simulation for Nokia's tone solution was distributed in the August meeting and no further update of this solution was provided. In [5], it was reported that the tone solution did not meet the character error requirements for degraded channels. Also, Lucent found that Nokia's tone solution, when interoperating with an unmodified decoder, did not work with real devices. Because of its obvious deficiencies, the lack of an updated simulation, and time constraints, Nokia's tone solution was not tested further.

The tables in the following sections present results for the TTY conditions tested. The table entry for a candidate is shaded if it represents a failure of the tested condition. According to the file `readme.txt`, attached to email sent by Ericsson [7], their solution does not handle 50 baud, interactive character mode, nor interoperability. The table entries for these conditions are marked as failures.

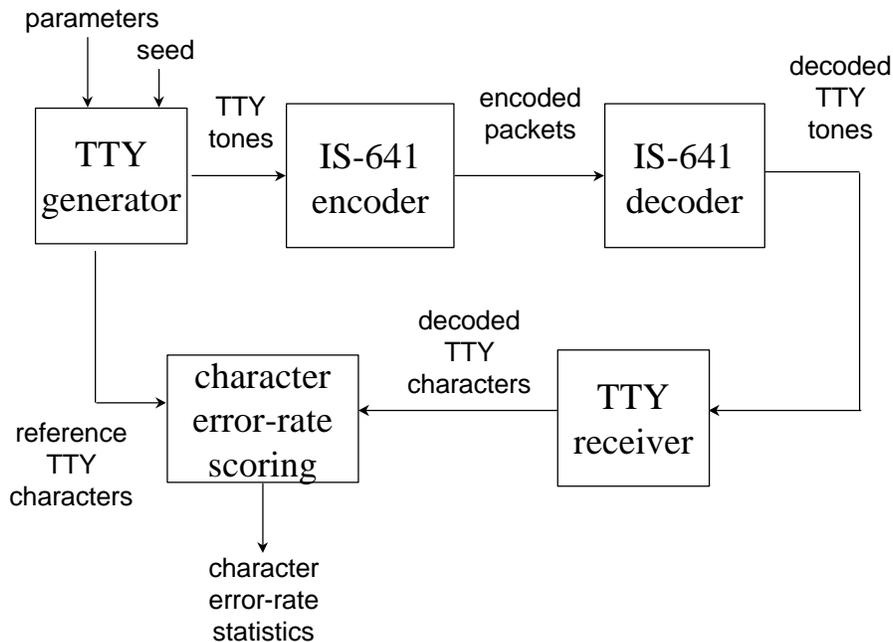
## 2. Nokia's Tone Solution

In [5], Nokia presented a TTY tone solution that is superimposes new tones over the Baudot tones to achieve robust transmission of the Baudot code. The premise of this solution is that it can meet the interoperability requirement because a TTY device can detect the Baudot tones despite the superimposed tones. In order to test this premise, 45.45 baud TTY tones with nominal values was processed by a modified encoder and an unmodified decoder. The decoded output was input to a commercially available TTY device. Errors above 10% were observed. Furthermore, it was reported in [5] that the tone solution did not meet the character error requirements for degraded channels. Because of the solution's obvious deficiencies, the lack of an updated simulation, and time constraints for conducting the testing, Nokia's tone solution was not tested further.

### 3. Parameter Variability

The TTY solutions were evaluated by testing the full range of TTY parameters, as specified by [8]. In order to generate Baudot tones over the full range of parameters as specified by the requirements, a TTY signal generator was developed based on the generator, [9], provided by HNS to the UWCC half-rate group for their TTY testing. The signal generator used for this testing is an extension of that software. The original HNS software generated a random character set, according to Lober and Walsh guidelines, [10], and the corresponding audio Baudot tones. The frequency and bit duration tolerances were user settable to be either fixed at nominal or randomly varying within a range. The software was augmented to allow the tolerances to be fixed at values other than nominal. The phase mode feature was maintained, allowing the starting phase of each bit's sine wave could be set to continue from the last bit (*continuous*), vary randomly, or shift 180 degrees for maximum discontinuity (*discontinuous*). The output signal level feature was also maintained. New features allow the user to set baud rate (45.45 or 50), and the number of stop-bits (between 1.0 and 2.0). Finally, the user may set the generator to stream characters or simulate interactive typing (by the insertion of silence gaps between characters of 50 to 600 ms). When in *interactive* mode, a mark-hold of up to 300 ms can be activated. This software generator allows complete control over the characteristics of the generated TTY signal. The testing methodology is presented in the figure below:

Figure 2.1. Parameter Variability - Test Methodology



1 Testing was performed to *exhaustively* exercise the range of the parameters. Requirement 1 was evaluated  
2 by varying the TTY frequencies  $\pm 4\%$  from nominal. Requirement 2 was evaluated by testing both  
3 continuous and discontinuous modes of the phase. Requirement 3 was evaluated by testing both 45.45 and  
4 50 baud, in addition to varying the bit length by +0.4 ms, -0.4 ms, and randomly between  $\pm 0.4$  ms.  
5 Requirement 7 was evaluated by testing signals with 1 and 2 stop bits. Requirement 8 was evaluated by  
6 testing the range of input levels (-16 dBov and -36 dBov). Requirement 13 is evaluated by testing both  
7 streaming and interactive TTY modes. Requirement 18 is evaluated by testing interactive mode with and  
8 without a mark-hold of 300 ms. Over 2000 characters were tested for each experiment. Printable  
9 character error rates were calculated using a UNIX “diff” based scoring method. The results are  
10 presented in the following tables.

11

**Table 2.1-a. Parameter Variability – 45 baud**

| #  | Baud | Freq. tol. (% Hz) | Phase (Continuous /Dis-con.) | Bit duration (ms) | Level (dBov) | Stop-bits | Streaming/ Interactive | Mark-hold (ms) | Lucent % PCER | Nokia (bypass) % PCER | Nokia (tone) % PCER | Ericsson % PCER |
|----|------|-------------------|------------------------------|-------------------|--------------|-----------|------------------------|----------------|---------------|-----------------------|---------------------|-----------------|
| 1  | 45   | +4,-4             | C                            | +0.4              | -16          | 1         | S                      | 0              | 0             | 0                     |                     |                 |
| 2  | 45   | +4,-4             | C                            | +0.4              | -16          | 1         | I                      | 0              | 0             | 0                     |                     |                 |
| 3  | 45   | +4,-4             | C                            | +0.4              | -16          | 1         | I                      | 300            | 0             | 0                     |                     |                 |
| 4  | 45   | +4,-4             | C                            | +0.4              | -16          | 2         | S                      | 0              | 0             | 0                     |                     |                 |
| 5  | 45   | +4,-4             | C                            | +0.4              | -16          | 2         | I                      | 0              | 0             | 0                     |                     |                 |
| 6  | 45   | +4,-4             | C                            | +0.4              | -16          | 2         | I                      | 300            | 0             | 0                     |                     |                 |
| 7  | 45   | +4,-4             | C                            | +0.4              | -36          | 1         | S                      | 0              | 0             | 0                     |                     |                 |
| 8  | 45   | +4,-4             | C                            | +0.4              | -36          | 1         | I                      | 0              | 0             | 0                     |                     |                 |
| 9  | 45   | +4,-4             | C                            | +0.4              | -36          | 1         | I                      | 300            | 0             | 0                     |                     |                 |
| 10 | 45   | +4,-4             | C                            | +0.4              | -36          | 2         | S                      | 0              | 0             | 0                     |                     |                 |
| 11 | 45   | +4,-4             | C                            | +0.4              | -36          | 2         | I                      | 0              | 0             | 0                     |                     |                 |
| 12 | 45   | +4,-4             | C                            | +0.4              | -36          | 2         | I                      | 300            | 0             | 0                     |                     |                 |
| 13 | 45   | +4,-4             | C                            | -0.4              | -16          | 1         | S                      | 0              | 0             | 74.35                 |                     |                 |
| 14 | 45   | +4,-4             | C                            | -0.4              | -16          | 1         | I                      | 0              | 0             | 0                     |                     |                 |
| 15 | 45   | +4,-4             | C                            | -0.4              | -16          | 1         | I                      | 300            | 0             | 0                     |                     |                 |
| 16 | 45   | +4,-4             | C                            | -0.4              | -16          | 2         | S                      | 0              | 0             | 0                     |                     |                 |
| 17 | 45   | +4,-4             | C                            | -0.4              | -16          | 2         | I                      | 0              | 0             | 0                     |                     |                 |
| 18 | 45   | +4,-4             | C                            | -0.4              | -16          | 2         | I                      | 300            | 0             | 0                     |                     |                 |
| 19 | 45   | +4,-4             | C                            | -0.4              | -36          | 1         | S                      | 0              | 0             | 74.45                 |                     |                 |
| 20 | 45   | +4,-4             | C                            | -0.4              | -36          | 1         | I                      | 0              | 0             | 0                     |                     |                 |
| 21 | 45   | +4,-4             | C                            | -0.4              | -36          | 1         | I                      | 300            | 0             | 0                     |                     |                 |
| 22 | 45   | +4,-4             | C                            | -0.4              | -36          | 2         | S                      | 0              | 0             | 0                     |                     |                 |
| 23 | 45   | +4,-4             | C                            | -0.4              | -36          | 2         | I                      | 0              | 0             | 0                     |                     |                 |
| 24 | 45   | +4,-4             | C                            | -0.4              | -36          | 2         | I                      | 300            | 0             | 0                     |                     |                 |
| 25 | 45   | +4,-4             | C                            | ±0.4              | -16          | 1         | S                      | 0              | 0             | 0                     |                     |                 |
| 26 | 45   | +4,-4             | C                            | ±0.4              | -16          | 1         | I                      | 0              | 0             | 0                     |                     |                 |
| 27 | 45   | +4,-4             | C                            | ±0.4              | -16          | 1         | I                      | 300            | 0             | 0                     |                     |                 |
| 28 | 45   | +4,-4             | C                            | ±0.4              | -16          | 2         | S                      | 0              | 0             | 0                     |                     |                 |
| 29 | 45   | +4,-4             | C                            | ±0.4              | -16          | 2         | I                      | 0              | 0             | 0                     |                     |                 |
| 30 | 45   | +4,-4             | C                            | ±0.4              | -16          | 2         | I                      | 300            | 0             | 0                     |                     |                 |
| 31 | 45   | +4,-4             | C                            | ±0.4              | -36          | 1         | S                      | 0              | 0             | 0                     |                     |                 |
| 32 | 45   | +4,-4             | C                            | ±0.4              | -36          | 1         | I                      | 0              | 0             | 0                     |                     |                 |
| 33 | 45   | +4,-4             | C                            | ±0.4              | -36          | 1         | I                      | 300            | 0             | 0                     |                     |                 |
| 34 | 45   | +4,-4             | C                            | ±0.4              | -36          | 2         | S                      | 0              | 0             | 0                     |                     |                 |
| 35 | 45   | +4,-4             | C                            | ±0.4              | -36          | 2         | I                      | 0              | 0             | 0                     |                     |                 |
| 36 | 45   | +4,-4             | C                            | ±0.4              | -36          | 2         | I                      | 300            | 0             | 0                     |                     |                 |

**Table 2.1-b. Parameter Variability – 45 baud**

| #  | Baud | Freq. tol. (% Hz) | Phase (Continuous /Dis-con.) | Bit duration (ms) | Level (dBov) | Stop-bits | Streaming/ Interactive | Mark-hold (ms) | Lucent % PCER | Nokia (bypass) % PCER | Nokia (tone) % PCER | Ericsson % PCER |
|----|------|-------------------|------------------------------|-------------------|--------------|-----------|------------------------|----------------|---------------|-----------------------|---------------------|-----------------|
| 37 | 45   | +4,-4             | D                            | +0.4              | -16          | 1         | S                      | 0              | 0             | 0                     |                     |                 |
| 38 | 45   | +4,-4             | D                            | +0.4              | -16          | 1         | I                      | 0              | 0             | 0                     |                     |                 |
| 39 | 45   | +4,-4             | D                            | +0.4              | -16          | 1         | I                      | 300            | 0             | 0                     |                     |                 |
| 40 | 45   | +4,-4             | D                            | +0.4              | -16          | 2         | S                      | 0              | 0             | 0                     |                     |                 |
| 41 | 45   | +4,-4             | D                            | +0.4              | -16          | 2         | I                      | 0              | 0             | 0                     |                     |                 |
| 42 | 45   | +4,-4             | D                            | +0.4              | -16          | 2         | I                      | 300            | 0             | 0                     |                     |                 |
| 43 | 45   | +4,-4             | D                            | +0.4              | -36          | 1         | S                      | 0              | 0             | 0                     |                     |                 |
| 44 | 45   | +4,-4             | D                            | +0.4              | -36          | 1         | I                      | 0              | 0             | 0                     |                     |                 |
| 45 | 45   | +4,-4             | D                            | +0.4              | -36          | 1         | I                      | 300            | 0             | 0                     |                     |                 |
| 46 | 45   | +4,-4             | D                            | +0.4              | -36          | 2         | S                      | 0              | 0             | 0                     |                     |                 |
| 47 | 45   | +4,-4             | D                            | +0.4              | -36          | 2         | I                      | 0              | 0             | 0                     |                     |                 |
| 48 | 45   | +4,-4             | D                            | +0.4              | -36          | 2         | I                      | 300            | 0             | 0                     |                     |                 |
| 49 | 45   | +4,-4             | D                            | -0.4              | -16          | 1         | S                      | 0              | 0             | 74.35                 |                     |                 |
| 50 | 45   | +4,-4             | D                            | -0.4              | -16          | 1         | I                      | 0              | 0             | 0                     |                     |                 |
| 51 | 45   | +4,-4             | D                            | -0.4              | -16          | 1         | I                      | 300            | 0             | 0                     |                     |                 |
| 52 | 45   | +4,-4             | D                            | -0.4              | -16          | 2         | S                      | 0              | 0             | 0                     |                     |                 |
| 53 | 45   | +4,-4             | D                            | -0.4              | -16          | 2         | I                      | 0              | 0             | 0                     |                     |                 |
| 54 | 45   | +4,-4             | D                            | -0.4              | -16          | 2         | I                      | 300            | 0             | 0                     |                     |                 |
| 55 | 45   | +4,-4             | D                            | -0.4              | -36          | 1         | S                      | 0              | 0             | 74.35                 |                     |                 |
| 56 | 45   | +4,-4             | D                            | -0.4              | -36          | 1         | I                      | 0              | 0             | 0                     |                     |                 |
| 57 | 45   | +4,-4             | D                            | -0.4              | -36          | 1         | I                      | 300            | 0             | 0                     |                     |                 |
| 58 | 45   | +4,-4             | D                            | -0.4              | -36          | 2         | S                      | 0              | 0             | 0                     |                     |                 |
| 59 | 45   | +4,-4             | D                            | -0.4              | -36          | 2         | I                      | 0              | 0             | 0                     |                     |                 |
| 60 | 45   | +4,-4             | D                            | -0.4              | -36          | 2         | I                      | 300            | 0             | 0                     |                     |                 |
| 61 | 45   | +4,-4             | D                            | ±0.4              | -16          | 1         | S                      | 0              | 0             | 0                     |                     |                 |
| 62 | 45   | +4,-4             | D                            | ±0.4              | -16          | 1         | I                      | 0              | 0             | 0                     |                     |                 |
| 63 | 45   | +4,-4             | D                            | ±0.4              | -16          | 1         | I                      | 300            | 0             | 0                     |                     |                 |
| 64 | 45   | +4,-4             | D                            | ±0.4              | -16          | 2         | S                      | 0              | 0             | 0                     |                     |                 |
| 65 | 45   | +4,-4             | D                            | ±0.4              | -16          | 2         | I                      | 0              | 0             | 0                     |                     |                 |
| 66 | 45   | +4,-4             | D                            | ±0.4              | -16          | 2         | I                      | 300            | 0             | 0                     |                     |                 |
| 67 | 45   | +4,-4             | D                            | ±0.4              | -36          | 1         | S                      | 0              | 0             | 0                     |                     |                 |
| 68 | 45   | +4,-4             | D                            | ±0.4              | -36          | 1         | I                      | 0              | 0             | 0                     |                     |                 |
| 69 | 45   | +4,-4             | D                            | ±0.4              | -36          | 1         | I                      | 300            | 0             | 0                     |                     |                 |
| 70 | 45   | +4,-4             | D                            | ±0.4              | -36          | 2         | S                      | 0              | 0             | 0                     |                     |                 |
| 71 | 45   | +4,-4             | D                            | ±0.4              | -36          | 2         | I                      | 0              | 0             | 0                     |                     |                 |
| 72 | 45   | +4,-4             | D                            | ±0.4              | -36          | 2         | I                      | 300            | 0             | 0                     |                     |                 |

**Table 2.2-a. Parameter Variability – 50 baud**

| #  | Baud | Freq. tol. (% Hz) | Phase (Continuous /Dis-con.) | Bit duration (ms) | Level (dBov) | Stop-bits | Streaming/ Interactive | Mark-hold (ms) | Lucent % PCER | Nokia (bypass) % PCER | Nokia (tone) % PCER | Ericsson % PCER |
|----|------|-------------------|------------------------------|-------------------|--------------|-----------|------------------------|----------------|---------------|-----------------------|---------------------|-----------------|
| 1  | 50   | +4,-4             | C                            | +0.4              | -16          | 1         | S                      | 0              | 0             | 85.60                 |                     |                 |
| 2  | 50   | +4,-4             | C                            | +0.4              | -16          | 1         | I                      | 0              | 0             | 61.20                 |                     |                 |
| 3  | 50   | +4,-4             | C                            | +0.4              | -16          | 1         | I                      | 300            | 0             | 74.65                 |                     |                 |
| 4  | 50   | +4,-4             | C                            | +0.4              | -16          | 2         | S                      | 0              | 0             | 30.00                 |                     |                 |
| 5  | 50   | +4,-4             | C                            | +0.4              | -16          | 2         | I                      | 0              | 0             | 25.15                 |                     |                 |
| 6  | 50   | +4,-4             | C                            | +0.4              | -16          | 2         | I                      | 300            | 0             | 29.55                 |                     |                 |
| 7  | 50   | +4,-4             | C                            | +0.4              | -36          | 1         | S                      | 0              | 0             | 83.70                 |                     |                 |
| 8  | 50   | +4,-4             | C                            | +0.4              | -36          | 1         | I                      | 0              | 0             | 54.95                 |                     |                 |
| 9  | 50   | +4,-4             | C                            | +0.4              | -36          | 1         | I                      | 300            | 0             | 73.90                 |                     |                 |
| 10 | 50   | +4,-4             | C                            | +0.4              | -36          | 2         | S                      | 0              | 0             | 29.55                 |                     |                 |
| 11 | 50   | +4,-4             | C                            | +0.4              | -36          | 2         | I                      | 0              | 0             | 25.40                 |                     |                 |
| 12 | 50   | +4,-4             | C                            | +0.4              | -36          | 2         | I                      | 300            | 0             | 29.15                 |                     |                 |
| 13 | 50   | +4,-4             | C                            | -0.4              | -16          | 1         | S                      | 0              | 0             | 74.85                 |                     |                 |
| 14 | 50   | +4,-4             | C                            | -0.4              | -16          | 1         | I                      | 0              | 0             | 50.25                 |                     |                 |
| 15 | 50   | +4,-4             | C                            | -0.4              | -16          | 1         | I                      | 300            | 0             | 82.30                 |                     |                 |
| 16 | 50   | +4,-4             | C                            | -0.4              | -16          | 2         | S                      | 0              | 0             | 84.45                 |                     |                 |
| 17 | 50   | +4,-4             | C                            | -0.4              | -16          | 2         | I                      | 0              | 0             | 79.25                 |                     |                 |
| 18 | 50   | +4,-4             | C                            | -0.4              | -16          | 2         | I                      | 300            | 0             | 79.15                 |                     |                 |
| 19 | 50   | +4,-4             | C                            | -0.4              | -36          | 1         | S                      | 0              | 0             | 67.20                 |                     |                 |
| 20 | 50   | +4,-4             | C                            | -0.4              | -36          | 1         | I                      | 0              | 0             | 40.60                 |                     |                 |
| 21 | 50   | +4,-4             | C                            | -0.4              | -36          | 1         | I                      | 300            | 0             | 81.05                 |                     |                 |
| 22 | 50   | +4,-4             | C                            | -0.4              | -36          | 2         | S                      | 0              | 0             | 84.35                 |                     |                 |
| 23 | 50   | +4,-4             | C                            | -0.4              | -36          | 2         | I                      | 0              | 0             | 79.00                 |                     |                 |
| 24 | 50   | +4,-4             | C                            | -0.4              | -36          | 2         | I                      | 300            | 0             | 79.10                 |                     |                 |
| 25 | 50   | +4,-4             | C                            | ±0.4              | -16          | 1         | S                      | 0              | 0             | 70.55                 |                     |                 |
| 26 | 50   | +4,-4             | C                            | ±0.4              | -16          | 1         | I                      | 0              | 0             | 38.45                 |                     |                 |
| 27 | 50   | +4,-4             | C                            | ±0.4              | -16          | 1         | I                      | 300            | 0             | 79.50                 |                     |                 |
| 28 | 50   | +4,-4             | C                            | ±0.4              | -16          | 2         | S                      | 0              | 0             | 79.50                 |                     |                 |
| 29 | 50   | +4,-4             | C                            | ±0.4              | -16          | 2         | I                      | 0              | 0             | 72.15                 |                     |                 |
| 30 | 50   | +4,-4             | C                            | ±0.4              | -16          | 2         | I                      | 300            | 0             | 71.75                 |                     |                 |
| 31 | 50   | +4,-4             | C                            | ±0.4              | -36          | 1         | S                      | 0              | 0             | 66.20                 |                     |                 |
| 32 | 50   | +4,-4             | C                            | ±0.4              | -36          | 1         | I                      | 0              | 0             | 35.20                 |                     |                 |
| 33 | 50   | +4,-4             | C                            | ±0.4              | -36          | 1         | I                      | 300            | 0             | 78.85                 |                     |                 |
| 34 | 50   | +4,-4             | C                            | ±0.4              | -36          | 2         | S                      | 0              | 0             | 79.45                 |                     |                 |
| 35 | 50   | +4,-4             | C                            | ±0.4              | -36          | 2         | I                      | 0              | 0             | 71.70                 |                     |                 |
| 36 | 50   | +4,-4             | C                            | ±0.4              | -36          | 2         | I                      | 300            | 0             | 70.45                 |                     |                 |

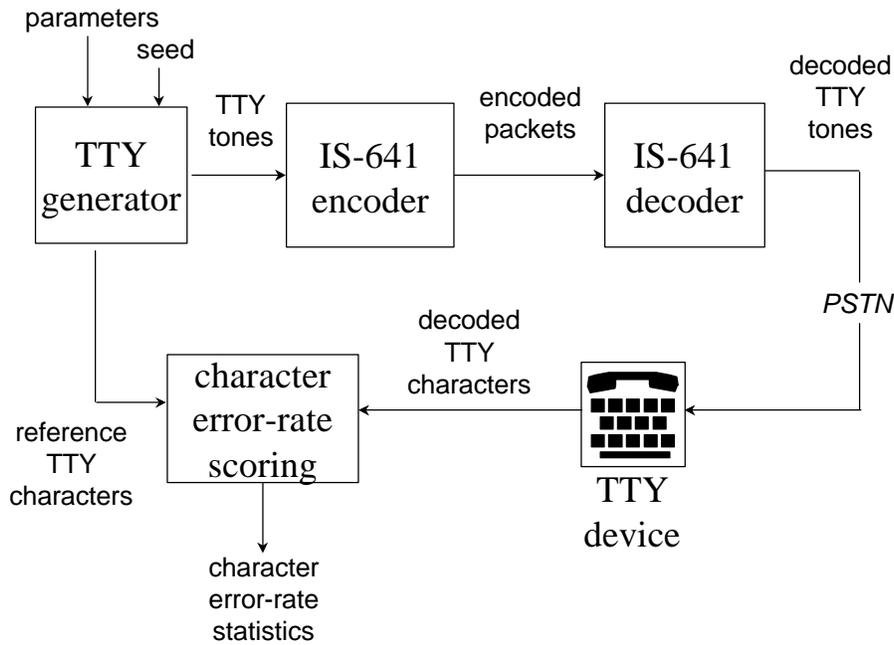
**Table 2.2-b. Parameter Variability – 50 baud**

| #  | Baud | Freq. tol. (% Hz) | Phase (Continuous /Dis-con.) | Bit duration (ms) | Level (dBov) | Stop-bits | Streaming/ Interactive | Mark-hold (ms) | Lucent % PCER | Nokia (bypass) % PCER | Nokia (tone) % PCER | Ericsson % PCER |
|----|------|-------------------|------------------------------|-------------------|--------------|-----------|------------------------|----------------|---------------|-----------------------|---------------------|-----------------|
| 37 | 50   | +4,-4             | D                            | +0.4              | -16          | 1         | S                      | 0              | 0             | 29.85                 |                     |                 |
| 38 | 50   | +4,-4             | D                            | +0.4              | -16          | 1         | I                      | 0              | 0             | 27.15                 |                     |                 |
| 39 | 50   | +4,-4             | D                            | +0.4              | -16          | 1         | I                      | 300            | 0             | 31.55                 |                     |                 |
| 40 | 50   | +4,-4             | D                            | +0.4              | -16          | 2         | S                      | 0              | 0             | 22.05                 |                     |                 |
| 41 | 50   | +4,-4             | D                            | +0.4              | -16          | 2         | I                      | 0              | 0             | 26.50                 |                     |                 |
| 42 | 50   | +4,-4             | D                            | +0.4              | -16          | 2         | I                      | 300            | 0             | 27.15                 |                     |                 |
| 43 | 50   | +4,-4             | D                            | +0.4              | -36          | 1         | S                      | 0              | 0             | 22.00                 |                     |                 |
| 44 | 50   | +4,-4             | D                            | +0.4              | -36          | 1         | I                      | 0              | 0             | 17.35                 |                     |                 |
| 45 | 50   | +4,-4             | D                            | +0.4              | -36          | 1         | I                      | 300            | 0             | 26.45                 |                     |                 |
| 46 | 50   | +4,-4             | D                            | +0.4              | -36          | 2         | S                      | 0              | 0             | 11.15                 |                     |                 |
| 47 | 50   | +4,-4             | D                            | +0.4              | -36          | 2         | I                      | 0              | 0             | 15.95                 |                     |                 |
| 48 | 50   | +4,-4             | D                            | +0.4              | -36          | 2         | I                      | 300            | 0             | 18.40                 |                     |                 |
| 49 | 50   | +4,-4             | D                            | -0.4              | -16          | 1         | S                      | 0              | 0             | 50.35                 |                     |                 |
| 50 | 50   | +4,-4             | D                            | -0.4              | -16          | 1         | I                      | 0              | 0             | 33.60                 |                     |                 |
| 51 | 50   | +4,-4             | D                            | -0.4              | -16          | 1         | I                      | 300            | 0             | 57.45                 |                     |                 |
| 52 | 50   | +4,-4             | D                            | -0.4              | -16          | 2         | S                      | 0              | 0             | 46.00                 |                     |                 |
| 53 | 50   | +4,-4             | D                            | -0.4              | -16          | 2         | I                      | 0              | 0             | 25.95                 |                     |                 |
| 54 | 50   | +4,-4             | D                            | -0.4              | -16          | 2         | I                      | 300            | 0             | 66.35                 |                     |                 |
| 55 | 50   | +4,-4             | D                            | -0.4              | -36          | 1         | S                      | 0              | 0             | 31.15                 |                     |                 |
| 56 | 50   | +4,-4             | D                            | -0.4              | -36          | 1         | I                      | 0              | 0             | 20.90                 |                     |                 |
| 57 | 50   | +4,-4             | D                            | -0.4              | -36          | 1         | I                      | 300            | 0             | 48.90                 |                     |                 |
| 58 | 50   | +4,-4             | D                            | -0.4              | -36          | 2         | S                      | 0              | 0             | 26.25                 |                     |                 |
| 59 | 50   | +4,-4             | D                            | -0.4              | -36          | 2         | I                      | 0              | 0             | 16.20                 |                     |                 |
| 60 | 50   | +4,-4             | D                            | -0.4              | -36          | 2         | I                      | 300            | 0             | 57.80                 |                     |                 |
| 61 | 50   | +4,-4             | D                            | ±0.4              | -16          | 1         | S                      | 0              | 0             | 30.40                 |                     |                 |
| 62 | 50   | +4,-4             | D                            | ±0.4              | -16          | 1         | I                      | 0              | 0             | 18.25                 |                     |                 |
| 63 | 50   | +4,-4             | D                            | ±0.4              | -16          | 1         | I                      | 300            | 0             | 30.50                 |                     |                 |
| 64 | 50   | +4,-4             | D                            | ±0.4              | -16          | 2         | S                      | 0              | 0             | 23.35                 |                     |                 |
| 65 | 50   | +4,-4             | D                            | ±0.4              | -16          | 2         | I                      | 0              | 0             | 19.95                 |                     |                 |
| 66 | 50   | +4,-4             | D                            | ±0.4              | -16          | 2         | I                      | 300            | 0             | 38.50                 |                     |                 |
| 67 | 50   | +4,-4             | D                            | ±0.4              | -36          | 1         | S                      | 0              | 0             | 17.45                 |                     |                 |
| 68 | 50   | +4,-4             | D                            | ±0.4              | -36          | 1         | I                      | 0              | 0             | 9.40                  |                     |                 |
| 69 | 50   | +4,-4             | D                            | ±0.4              | -36          | 1         | I                      | 300            | 0             | 23.10                 |                     |                 |
| 70 | 50   | +4,-4             | D                            | ±0.4              | -36          | 2         | S                      | 0              | 0             | 14.50                 |                     |                 |
| 71 | 50   | +4,-4             | D                            | ±0.4              | -36          | 2         | I                      | 0              | 0             | 11.25                 |                     |                 |
| 72 | 50   | +4,-4             | D                            | ±0.4              | -36          | 2         | I                      | 300            | 0             | 30.00                 |                     |                 |

## 4. Hardware Receiver

The TTY solutions were tested using TTY hardware for receiving TTY tones. The figure below presents the testing methodology:

**Figure 3.1. HW Receiver - Test Methodology**



The previous testing with the software TTY generator demonstrated the capability of the TTY solutions detector to recognize signals with frequency, phase, mark-hold, and input level deviations. Since TTY solutions involve regenerating nominal tones in the decoder regardless of what deviations these parameters had in the encoder, these parameters were all set to nominal values (frequency tolerance = 0, phase mode = discontinuous, mark-hold = 0, and level = -26 dBov) for this testing. TTY tones were generated for over 4000 characters with bit-length set to test the shortest and longest duration. The shortest characters had a bit duration shortened by 0.4 ms, and only one stop bit. The longest characters had a bit duration lengthened by 0.4 ms, and two stop bits. The results are presented in the table below:

**Table 3.1. HW Receiver - TTY Test Results**

| # | Baud | Bit duration (ms) | Stop-bits | Streaming/Interactive | Lucent % PCER | Nokia (bypass) % PCER | Nokia (tone) % PCER | Ericsson % PCER |
|---|------|-------------------|-----------|-----------------------|---------------|-----------------------|---------------------|-----------------|
| 1 | 45   | -0.4              | 1         | S                     | *             | *                     | *                   | *               |
| 2 | 45   | -0.4              | 1         | I                     | 0             | 0                     |                     |                 |
| 3 | 45   | +0.4              | 2         | S                     | 0             | 0                     |                     |                 |
| 4 | 45   | +0.4              | 2         | I                     | 0             | 0                     |                     |                 |

|   |    |      |   |   |      |       |   |   |
|---|----|------|---|---|------|-------|---|---|
| 5 | 50 | -0.4 | 1 | S | *    | *     | * | * |
| 6 | 50 | -0.4 | 1 | I | 0    | 6.88  |   |   |
| 7 | 50 | +0.4 | 2 | S | 0.05 | 28.06 |   |   |
| 8 | 50 | +0.4 | 2 | I | 0.12 | 40.58 |   |   |

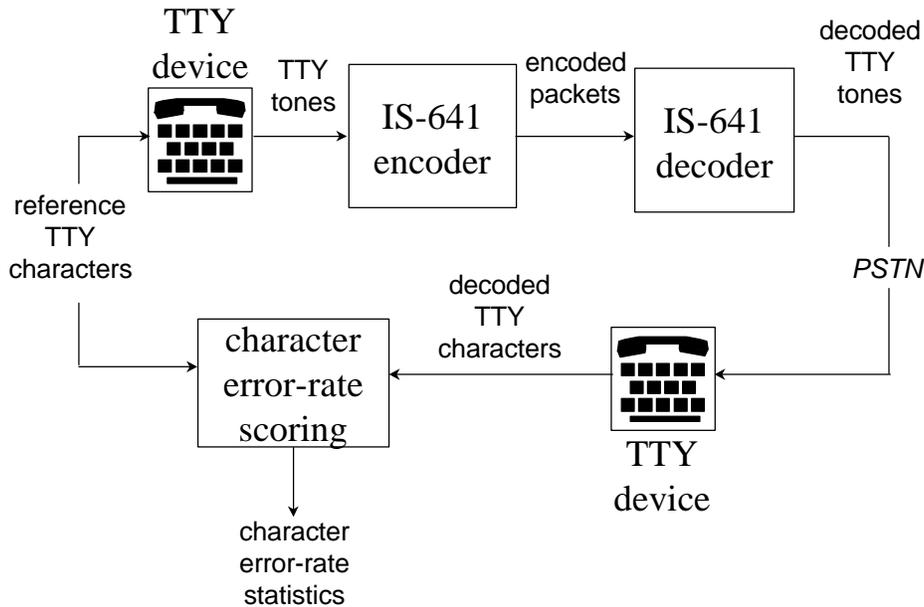
1 \* Conditions 1 and 4 could not be tested because the TTY hardware device could not handle streaming data with short bit length and only  
 2 1 stop bit.

3

## 4 5. Hardware Transmitter / Hardware Receiver

5 The TTY solutions were tested using TTY hardware for both transmitting and receiving TTY tones. The  
 6 figure below presents the testing methodology:

7 **Figure 4.1. HW Transmit / HW Receive - Test Methodology**



8

9 Since an actual TTY hardware device was used, we had no control over the parameters although the TTY  
 10 signals were 45-baud tones. Over 4000 characters were tested. The performance result are presented in  
 11 the following table:

12 **Table 4.1. HW Transmit / HW Receive - TTY Test Results**

| # | Lucent<br>% PCER | Nokia (bypass)<br>% PCER | Nokia (tone)<br>% PCER | Ericsson<br>% PCER |
|---|------------------|--------------------------|------------------------|--------------------|
| 1 | 0                | 0                        |                        |                    |

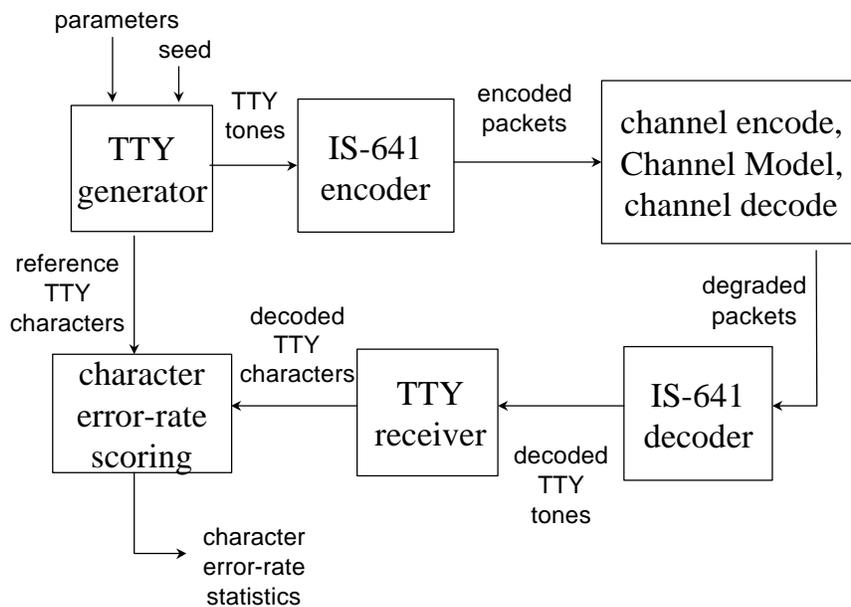
13

14

## 6. Degraded Channel

Previous testing has stressed the TTY solution's ability to detect TTY tones over a wide range of parameter variability. This testing evaluated the performance of the TTY solutions in degraded channels. To isolate the channel performance, the software TTY generator was used to generate the TTY input tones for over 4000 characters at 45 baud and the parameters were all set to nominal values. Both streaming and interactive modes were tested. A channel model was used to simulate Raleigh fading at any C/N and fading frequency. The modulation was  $\pi/4$ -DQPSK with coherent detection. This is the same model used for the UWCC half-rate program. The figure below presents the testing methodology:

**Figure 5.1. TTY Degraded Channel Test Methodology**



The results for the degraded channel testing are presented in the table below. Results for the unmodified TIA/EIA 136-410 vocoder are included for comparison

**Table 5.1-a. TTY Test Results for Degraded Channels – Streaming Mode (Modified Encoder – Modified Decoder)\***

| # | C/N       | TIA/EIA 136-410 % PCER | Lucent % PCER | Nokia (bypass) % PCER | Nokia (tone) % PCER | Ericsson % PCER |
|---|-----------|------------------------|---------------|-----------------------|---------------------|-----------------|
| 1 | No-errors | 0.43                   | 0             | 0                     |                     |                 |
| 2 | 28 dB     | 0.68                   | 0             | 0                     |                     |                 |
| 3 | 26 dB     | 1.13                   | 0             | 0                     |                     |                 |
| 4 | 24 dB     | 1.75                   | 0             | 0                     |                     |                 |
| 5 | 22 dB     | 4.10                   | 0             | 0                     |                     |                 |
| 6 | 20 dB     | 7.72                   | 0             | 0                     |                     |                 |
| 7 | 18 dB     | 13.05                  | 0             | 0                     |                     |                 |
| 8 | 16 dB     | 20.35                  | 0             | 0                     |                     |                 |

|    |       |       |     |   |  |  |
|----|-------|-------|-----|---|--|--|
| 9  | 14 dB | 34.05 | 0   | 0 |  |  |
| 10 | 12 dB | 49.55 | 0.1 | 0 |  |  |
| 11 | 10 dB | 67.18 | 0.8 | 0 |  |  |

\* TIA/EIA 136-410 results were computed form an *unmodified* encoder operating with an *unmodified* decoder.

**Table 5.1-b. TTY Test Results for Degraded Channels – Interactive Mode  
 (Modified Encoder – Modified Decoder)\***

| #  | C/N       | TIA/EIA<br>136-410<br>% PCER | Lucent<br>% PCER | Nokia (bypass)<br>% PCER | Nokia (tone)<br>% PCER | Ericsson<br>% PCER |
|----|-----------|------------------------------|------------------|--------------------------|------------------------|--------------------|
| 1  | No-errors | 0.58                         | 0                | 0                        |                        |                    |
| 2  | 28 dB     | 1.10                         | 0                | 0                        |                        |                    |
| 3  | 26 dB     | 1.50                         | 0                | 0                        |                        |                    |
| 4  | 24 dB     | 2.17                         | 0                | 0                        |                        |                    |
| 5  | 22 dB     | 4.05                         | 0                | 0                        |                        |                    |
| 6  | 20 dB     | 6.48                         | 0                | 0                        |                        |                    |
| 7  | 18 dB     | 11.28                        | 0                | 0                        |                        |                    |
| 8  | 16 dB     | 19.37                        | 0                | 0                        |                        |                    |
| 9  | 14 dB     | 31.90                        | 0                | 0                        |                        |                    |
| 10 | 12 dB     | 48.57                        | 0                | 0                        |                        |                    |
| 11 | 10 dB     | 65.87                        | 0.28             | 0                        |                        |                    |

\* TIA/EIA 136-410 results were computed form an *unmodified* encoder operating with an *unmodified* decoder.

## 7. Interoperability

This testing evaluated the capability of the TTY solutions to interoperate with an unmodified vocoder in degraded channels. As in the previous degraded channel testing, the software TTY generator was used to generate the TTY input tones for over 4000 characters and the parameters were all set to nominal values so the channel performance could be isolated. Both streaming and interactive modes were tested. The channel model described previously was used.

The results for the interoperability testing are presented in the table below. Results for the unmodified TIA/EIA 136-410 vocoder are included for comparison; the TTY solutions should perform no worse than this.

**Table 6.1-a. TTY Test Results for Degraded Channels – Streaming Mode  
 (Modified Encoder – Unmodified Decoder)\***

| # | C/N       | TIA/EIA<br>136-410<br>% PCER | Lucent<br>% PCER | Nokia (bypass)<br>% PCER | Nokia (tone)<br>% PCER | Ericsson<br>% PCER |
|---|-----------|------------------------------|------------------|--------------------------|------------------------|--------------------|
| 1 | No-errors | 0.43                         | 0.07             | 0                        |                        |                    |
| 2 | 28 dB     | 0.68                         | 0.20             | 0.68                     |                        |                    |
| 3 | 26 dB     | 1.13                         | 0.65             | 0.63                     |                        |                    |
| 4 | 24 dB     | 1.75                         | 1.08             | 1.20                     |                        |                    |

|    |       |       |       |       |  |  |
|----|-------|-------|-------|-------|--|--|
| 5  | 22 dB | 4.10  | 2.80  | 1.60  |  |  |
| 6  | 20 dB | 7.72  | 5.85  | 3.85  |  |  |
| 7  | 18 dB | 13.05 | 9.83  | 7.95  |  |  |
| 8  | 16 dB | 20.35 | 19.25 | 13.53 |  |  |
| 9  | 14 dB | 34.05 | 31.98 | 23.05 |  |  |
| 10 | 12 dB | 49.55 | 47.57 | 36.40 |  |  |
| 11 | 10 dB | 67.18 | 65.60 | 55.55 |  |  |
| 12 | 8 dB  | 81.05 | 80.87 | 70.25 |  |  |

1 \* TIA/EIA 136-410 results were computed form an *unmodified* encoder operating with an unmodified decoder.

2

3 **Table 6.1-b. TTY Test Results for Degraded Channels – Interactive Mode**  
 4 **(Modified Encoder – Unmodified Decoder)\***

| #  | C/N       | TIA/EIA<br>136-410<br>% PCER | Lucent<br>% PCER | Nokia (bypass)<br>% PCER | Nokia (tone)<br>% PCER | Ericsson<br>% PCER |
|----|-----------|------------------------------|------------------|--------------------------|------------------------|--------------------|
| 1  | No-errors | 0.58                         | 0.52             | 1.15                     |                        |                    |
| 2  | 28 dB     | 1.10                         | 1.15             | 1.30                     |                        |                    |
| 3  | 26 dB     | 1.50                         | 1.35             | 1.53                     |                        |                    |
| 4  | 24 dB     | 2.17                         | 1.98             | 2.05                     |                        |                    |
| 5  | 22 dB     | 4.05                         | 3.73             | 2.82                     |                        |                    |
| 6  | 20 dB     | 6.48                         | 6.50             | 4.50                     |                        |                    |
| 7  | 18 dB     | 11.28                        | 10.93            | 7.82                     |                        |                    |
| 8  | 16 dB     | 19.37                        | 18.57            | 13.12                    |                        |                    |
| 9  | 14 dB     | 31.90                        | 32.17            | 19.18                    |                        |                    |
| 10 | 12 dB     | 48.57                        | 47.98            | 35.80                    |                        |                    |
| 11 | 10 dB     | 65.87                        | 65.22            | 54.22                    |                        |                    |
| 12 | 8 dB      | 80.95                        | 81.00            | 68.80                    |                        |                    |

5 \* TIA/EIA 136-410 results were computed form an *unmodified* encoder operating with an unmodified decoder.

6 The requirements state that performance shall be no worse than the unmodified TIA/EIA 136-410  
 7 vocoder. For the interoperability results above, however, differences of less than one percent were not  
 8 marked as a failure of the condition.

9 **8. False Alarms**

10 The ability of each solution to pass non-TTY signals was tested by processing data from speech databases  
 11 that have been used in past TIA vocoder evaluations, as well as music files, especially those that have  
 12 spectral information in the region of TTY tones. Constant sinusoidal signals at the TTY frequencies were  
 13 tested to see that the tones were not blocked or recognized as TTY character information.

14 **Table 7.1. TTY False-Alarm Test Results**

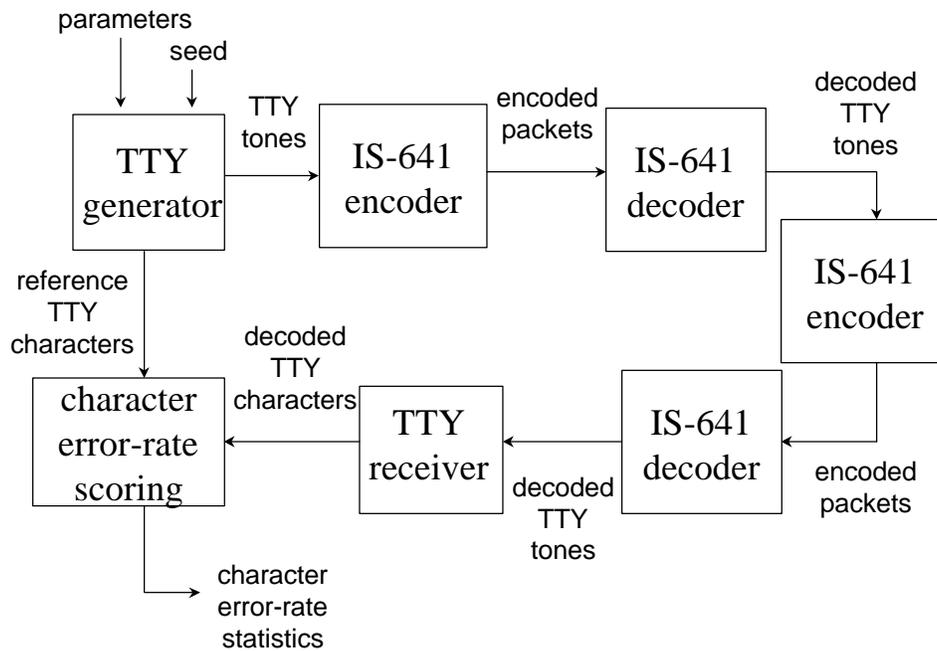
| # | Condition            | Lucent | Nokia<br>(bypass) | Nokia<br>(tone) | Ericsson |
|---|----------------------|--------|-------------------|-----------------|----------|
| 1 | Speech (4000 frames) | pass   | pass              |                 |          |
| 2 | 1800 Hz tone         | pass   | pass              |                 |          |

|   |                     |      |      |  |  |
|---|---------------------|------|------|--|--|
| 3 | Music 1 (violin)    | pass | fail |  |  |
| 4 | Music 2 (flute)     | pass | fail |  |  |
| 5 | Music 3 (xylophone) | pass | fail |  |  |

## 9. Tandem

The ability to operate in mobile-to-mobile conditions is required for voice and any TTY solution must demonstrate acceptable performance during tandem operation. The figure below presents the testing methodology:

**Figure 8.1. TTY Tandem Test Methodology**



For tandem testing, TTY signals for over 2000 characters were generated at 45 baud and nominal parameter settings. Both streaming and interactive modes of operation were examined. There were no channel degradations. These parameter settings were chosen because the TTY solutions (Lucent and Nokia) handled one encoding without introducing errors. The results for the degraded channel testing are presented in the table below.

**Table 8.1. TTY Tandem Test Results**

| # | Streaming/<br>Interactive | Lucent<br>% PCER | Nokia (bypass)<br>% PCER | Nokia (tone)<br>% PCER | Ericsson<br>% PCER |
|---|---------------------------|------------------|--------------------------|------------------------|--------------------|
| 1 | S                         | 0                | 0                        |                        |                    |
| 2 | I                         | 0                | 4.53                     |                        |                    |

## 10. Complexity

The table below presents the complexity estimates as reported by each candidate. The complexity of the Nokia tone solution has not been reported, but since it has to do what the bypass solution does plus additional detection and generation of tones, the complexity will be greater than the bypass solution. The complexity details of the Ericsson solution has not been reported, but like the Nokia tone solution, it must incorporate additional detection and generation of tones, making the complexity greater than either the Lucent or the Nokia bypass solutions.

**Table 9.1. Complexity Estimates**

|                                       | Lucent* | Nokia*<br>(bypass) | Nokia<br>(tone) | Ericsson |
|---------------------------------------|---------|--------------------|-----------------|----------|
| Program ROM                           | 800     | 600                | >600?           | ?        |
| Data ROM (words)                      | 64      | 102                | >102?           | ?        |
| Static RAM (words)                    | 40      | 60                 | >60?            | ?        |
| Dynamic RAM (words)                   | 41      | 500                | >500?           | ?        |
| Encoder Complexity (worst case WMOPS) | 0.027   | 0.16               | >0.16?          | <1.5     |
| Decoder Complexity (worst case WMOPS) | 0.068   | 0.06               | >0.06?          |          |

\* Lucent data from [2], Nokia data from [4], Ericsson data from [6].

## 11. Summary of Results

The table below presents a summary of the results.

**Table 10.1. Summary of Results**

| #  | Experiment                      | Number of<br>Conditions | Lucent<br>(#fail) | Nokia<br>(bypass)<br>(# fail) | Nokia<br>(tone)<br>(# fail) | Ericsson<br>(# fail) |
|----|---------------------------------|-------------------------|-------------------|-------------------------------|-----------------------------|----------------------|
| 1  | Parameter variability (45 baud) | 72                      | 0                 | 4                             |                             | 48                   |
| 2  | Parameter variability (50 baud) | 72                      | 0                 | 72                            |                             | 72                   |
| 3  | Hardware Receiver               | 6                       | 0                 | 3                             |                             | 5                    |
| 4  | Hardware Transmitter / Receiver | 1                       | 0                 | 0                             |                             |                      |
| 5  | Degraded Channel (streaming)    | 12                      | 0                 | 0                             |                             |                      |
| 6  | Degraded Channel (interactive)  | 12                      | 0                 | 0                             |                             | 12                   |
| 7  | Interoperability (streaming)    | 12                      | 0                 | 0                             |                             | 12                   |
| 8  | Interoperability (interactive)  | 12                      | 0                 | 0                             |                             | 12                   |
| 9  | False alarms                    | 5                       | 0                 | 3                             |                             |                      |
| 10 | Tandem                          | 2                       | 0                 | 1                             |                             | 1                    |
|    | Total                           | 206                     | 0                 | 82                            |                             | 162                  |

## 12. Conclusions

The above tests demonstrate that Lucent's TTY solution is the only candidate that meets or exceeds all of the requirements. None of the other solutions pass all of the requirements.

Although Ericsson's solution was not tested, by Ericsson's own admission, their simulation is incomplete and does not currently pass all of the requirements.

Nokia's tone solution was only minimally tested because Nokia has already presented results that demonstrate that their solution does not meet the degraded channel requirements and Lucent found that the solution does not meet the interoperability requirement.

Nokia's bypass solution was found to be deficient in several areas. The solution is not capable of supporting 45.45 baud with short bits and 1 stop bit. Furthermore, not only does the solution not support 50 baud, but it degrades the performance of worse than if the vocoder was not modified. Most importantly, the Nokia bypass solution is prone to false alarms. Music files with spectral energy in the vicinity of the space tone caused Nokia's solution to mute. Finally, Nokia's solution does not tandem with itself. Their solution does not permit TTY users to make mobile-to-mobile calls with less than 1% character errors.

Lucent's TTY solution is the only solution that meets or exceeds all of the requirements. It is designed to be robust to false alarms by applying a more stringent criterion for detecting the first TTY character. Subsequent characters use a more relaxed criterion in order to provide error-free performance.

## 13. Recommendation

The Lucent TTY solution is the only solution that meets or exceeds all of the requirements in [8]. Given that the Lucent solution has minimal complexity and meets all of the requirements, and given that the alternative solutions are deficient, it is recommended that the Lucent TTY solution be adopted.

## 14. References

- [1] *Lucent TTY Solution, Version 2.0*, TR45.3.5/99.08.16.20 [software]; Lucent Technologies.
- [2] *TTY Requirements Testing*, TR45.3.5/99.08.16.16; Lucent Technologies.
- [3] *TTY Solution for IS641 Codec and Initial Evaluation of Other Solution*, TR45.3.5/99.06.15.05; Nokia.
- [4] *TTY/TDD Solution for IS641*, TR45.3.5/99.07.14.05; Nokia.
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- [9] *TTYGEN, Version 1.2* [software]; Distributed by email after UWCC.GTF.HRP meeting of June 15, 1995; Hughes Network Systems.

- 1 [10] *TTY Over Cellular Laboratory and Field Test Procedure IS-136 TDMA*; J. Lober, B. Walsh, et. al.;
- 2       September 13, 1998.
- 3