

## **DTMF DETECTOR Data Sheet**

The Data contained in the document is preliminary and is subject to change.

## TABLE OF CONTENTS

<b>1</b>	<b>INTRODUCTION .....</b>	<b>3</b>
1.1	FEATURES .....	3
1.2	COMPONENT LIST .....	3
1.3	ABBREVIATIONS .....	4
1.4	REFERENCES.....	4
<b>2</b>	<b>GENERAL DESCRIPTION.....</b>	<b>5</b>
2.1	A STANDARD APPROACH .....	5
2.2	THE PROPOSED APPROACH.....	5
<b>3</b>	<b>FUNCTIONAL OVERVIEW.....</b>	<b>7</b>
<b>4</b>	<b>API .....</b>	<b>8</b>
4.1	DATA STRUCTURES .....	8
4.1.1	<i>Data Base.....</i>	<i>8</i>
4.1.2	<i>Scratch pad .....</i>	<i>8</i>
4.1.3	<i>Configuration.....</i>	<i>8</i>
4.1.4	<i>DTMF Signal Measurements.....</i>	<i>10</i>
4.2	IALG INTERFACE .....	11
4.3	VENDOR SPECIFIC API .....	11
4.3.1	<i>Initialization.....</i>	<i>11</i>
4.3.2	<i>Control.....</i>	<i>11</i>
4.3.3	<i>Process.....</i>	<i>11</i>
<b>5</b>	<b>SPECIFICATIONS.....</b>	<b>13</b>
5.1	GENERAL .....	13
5.2	PERFORMANCE CHARACTERIZATION .....	13
5.2.1	<i>Default Configuration.....</i>	<i>13</i>
5.2.2	<i>Test Case 1: Composite: Dial Tone, Noise and Twist.....</i>	<i>14</i>
5.2.3	<i>Test Case 2: Talk-Off Immunity and Threshold Variations.....</i>	<i>14</i>
5.2.4	<i>Test Case 3: Performance with AWGN.....</i>	<i>15</i>
5.2.5	<i>Test Case 4: Twist sensitivity .....</i>	<i>18</i>
5.2.6	<i>Test Case 5: Early Detection Latency.....</i>	<i>18</i>
5.2.7	<i>Test Case 6: Dial Tone Immunity .....</i>	<i>19</i>
5.2.8	<i>Test Case 7: Dynamic Range .....</i>	<i>20</i>
5.2.9	<i>Test Case 8: Tone Frequency Estimation Accuracy .....</i>	<i>21</i>
5.2.10	<i>Test Case 9: Low SNR Configuration and Performance.....</i>	<i>22</i>

## 1 Introduction

DTMF signaling was proposed more than 30 years ago to replace slower pulse dialing. Many things have changed since this time, but DTMF has become the most popular addressing and messaging tool in telecommunications, and it does not look as though it will fade away in foreseeable future.

Currently, there is no single standard that explicitly and exhaustively covers all issues connected to the detection of DTMF digits. There are several ITU documents (Q.23, Q.24), TIA/EIA-464B recommendations, Mitel and BellCore tests tape, as well as other sources, but even if taken together these do not provide complete coverage. BellCore test tape is the de-facto standard for talk-off performance testing; however, there is no standard test source for talk-down performance, necessary for an IVR system in which the DTMF signal is detected on the background of a voice echo. Mitel's test tape provides some useful tests, but it is incomplete and far from ideal.

Different applications, such as CO, IVR, PBX, VoX, and voice mail, have different requirements for DTMF detectors. Voice-over-packet applications require DTMF relay without introducing a long system delay, which is one of killing factors for VoIP telephony. Note that different countries have different views regarding what is an acceptable DTMF digit and what is not. Also, different countries have different dial tones and modifications (like stutter dial), which have to be accounted for. In some countries, PBXs use one kind of dial tone, while PSTN uses another.

### 1.1 Features

- Low MIPS: 0.25 /0.35 MIPS for 10 ms and 5 ms frame size versions respectively
- Designed as a telecom system component rather than a stand-alone algorithm.
- Can be configured on the fly, and such parameters as twists, frequency acceptance, spectrum cleanness, and signal duration thresholds can be altered during a call. The granularity of each parameter is about 0.25 dB (and 0.2 % for frequency acceptance margins).
- Early detection event (happening within 13...18 ms from the digit start) has the talk-off immunity in the range, allowed for complete DTMF digit detection (exact numbers depend on the configuration thresholds' settings). That allows significant shortening of the system delay in Voice Over Packet applications (low-latency DTMF relay).
- Does not use notch filters to suppress dial tone, so it tolerates relatively high-level echo dial tone (15...20 dB above DTMF level) even if its frequencies are quite different from the nominal, exceeding standard +/-0.5% tolerance. Moreover, different dial tones, such as single 400 Hz, are suppressed as North American ones are. The DTMF detector works in the presence of stutter dial tone (but less hot one).
- Provides estimates on the frequency and energy of detected digits, which may help carriers identify faulty CPE if customer complains arise.
- Wide dynamic range,
- High noise and talk-off immunity.
- Capable of satisfying requirements of any particular carrier in any country.

### 1.2 Component list

1. DTMF detector data sheet (this document)
2. Idtmf.h xDAIS-compliant header file.
3. Idtmf.c xDAIS-compliant C file with default configuration data.
4. Dtmf\_miket.h xDAIS-compliant header file.
5. Dtmf\_miket.l55 xDAIS-compliant library (5ms version).
6. Dtmf\_demo.zip archive with PC based demo program.

### **1.3 Abbreviations**

TBD

### **1.4 References**

TBD

## 2 General Description

### 2.1 A Standard Approach

In the beginning, DTMF detectors were built in hardware, with two filters for low and high band, and frequency counters to estimate the frequency of each tone. This was an expensive way to deal with address signaling. The first DSPs appeared in 80s. At that time, they had modest MIPS, very little internal fast memory, and only one accumulator. The theory of spectral analysis was not elaborate at that time and most of its methods were either low performance or highly complex. Thus, the Goertzel method of building DTMF detectors in software was used and became dominant—and it was adequate for the time. The detectors and IIR filters, directly or indirectly using the Goertzel method, are suffering from many disadvantages that are rooted in the method itself.

Goertzel-based DTMF detectors have the following limitations:

- Although they are memory efficient, they are not MIPS efficient.
- They have severe limitations on the dynamic range, due to IIR nature of Goertzel algorithm.
- The DTMF frequency plan has analog roots (each frequency is approximately 10.5% higher than the previous), so DTMF frequencies are unsuitable for block processing if real domain signal processing is used. As the consequence, energy estimates fluctuate from block to block, and it is impossible to gate the DTMF detector's decision precisely. This is one of the reasons why rejection and acceptance margins are usually so far apart.
- They can hardly benefit from modern DSP architectures, which are now very different from the first C1x devices.
- They are incapable of working with complex domain representation of the signal, which is essential for frequency content analysis. They ignore the achievements of applied spectral analysis, which became mature by mid-90s.
- They are hard to tune, customize, and test. This problem is the worst of all.

A typical Goertzel-based DTMF detector, available from some DSP algorithm companies and deemed 'field-proven,' is MIPS intensive, full of hard-coded constants, and difficult to port, customize, and maintain. The developers have spent lots of time on fixing numerous bugs to finally make it work in field conditions (they have learned complexity the hard way) with acceptable quality. Now they are afraid to touch the code because it might fall apart due to the change of a single instruction.

### 2.2 The Proposed Approach

The proposed DTMF detector was developed with all the aforementioned in mind.

It is not based on the Goertzel algorithm. It is based on multi-rate signal processing and modern complex domain applied spectral analysis methods and approaches. Frequency content analysis is optimized for short signals, and it provides reliable results. It takes advantage of C55x architecture with high degree of parallelism, dual MAC, and three simultaneous data read paths.

Express DSP compliant C55x DTMF detector software is proposed in two versions: one with a 5 ms frame size and one with a 10 ms frame size. The versions are quite similar in behavior. The version with a 10 ms frame size is faster, but the overall quality is higher in the 5 ms version, due to lower time granularity.

On a 200 MHz C5510, the 5 ms version of the DTMF detector will be capable of processing 384 channels (full capacity of 3 McBSPs on 8 Mbps), using only 70% of its MIPS ( $\mu$ /A-law companding in McBSP) and less than 30% of its internal memory space. That leaves enough system resources for the operating system, device drivers, built-in-test, control interface code, command and reply queues, data buffering, tone generation (about 0.1 MIPS / instance), selective channel data recording, and other light-weight features and future modifications. No external memory is needed.

The DTMF detector algorithm is complicated, but it has no magic—only well understood theory, appropriate to the problem and the DSP it runs on. As the result, this DTMF detector is fast, high quality, easy to use, customize and maintain.

### **3 Functional Overview**

Not disclosed in this document.

## 4 API

### 4.1 Data structures

#### 4.1.1 Data Base

Database is an object that keeps data, which should be preserved between calls to process incoming data. It should be properly initialized and shall not be overwritten by any other application. It may be moved into another location without limitations. The 'best' placement for database is internal DARAM, but performance shall not suffer drastically even if the database is placed in external RAM. If any performance problem arises, the object may be copied via DMA (in and out) a temporary location in internal RAM.

Database size:

- 98 Words (16 bit), long word (32 bit) alignment (5ms frame size)
- 78 Words, long word alignment (10ms frame size)

The content and meaning of particular fields of the database are undisclosed in this document.

#### 4.1.2 Scratch pad

Scratch pad is an object that is used during calls to process incoming data. It does not need to be initialized. It may be overwritten by any other application. It may reside in a new place each time a processing function is called: i.e. it may be moved into another location without limitations. The 'best' placement for database is internal DARAM. Performance will suffer drastically even if the database is placed in internal SARAM.

Scratch pad size:

- 190 Words, long word alignment (5ms frame size)
- 250 Words, long word alignment (10ms frame size)

The content and meaning of particular fields of the scratch pad are undisclosed in this document.

#### 4.1.3 Configuration

Configuration is an object, which contain important decision making parameters and it is referenced each time an input processing functions is called. The data there is READ-ONLY by DTMF functions. Many instances of DTMF detector may refer to the same instance of configuration data. The configuration data may be altered by external application on the fly. It is preferable that no associated DTMF detector is active (processes a valid DTMF signal) at the time of change.

Note that `Int` is defined in TI's supplied `ialg.h` file as 16 bit signed word.

```
typedef struct IDTMF_tCfg {
    Int  sNoiseThr;
    Int  sMinEnThr;
    Int  sSumEnThr;
    Int  sVarThr;
    Int  s2kUpThr;
    Int  sFwdTwistThr;
    Int  sRevTwistThr;
    Int  sPartThr;
    Int  sCleanThr;
    Int  sMaxFreqDevThr;
```

```

    Int sMinToneDuration;
    Int sMinPostSilenceDuration;
    Int sAbortTimeout;
} IDTMF_tCfg;

```

All relevant parameters are expressed in dB, scaled up with a coefficient, so that 3.0103 dB corresponds to 512. Thus 1 dB will correspond to approximately 170.083 ~ 170. The same definition is applied to Frequency deviation, but here 1% of frequency deviation corresponds to 170.083 (the same value).

The scaling was chosen as a compromise:

- to make log scale computation fast and simple;
- to allow enough breathing space to run averaging;
- leave some headroom for data manipulation;
- allow non-integer values;
- 0 corresponds to 0dBm signal (averaged over 40 samples), mu-law data (8159\*4 max);
- negative values are used for attenuated signal;
- min value corresponds to approx. -82.5 dBm;
- precision is about 0.25 dB.

The fields of configuration have the following meaning:

Parameter	Description	Recommended Range
<b>NoiseThr</b>	Maximum frame energy of background noise relative to signal level. It also covers the maximum level of the so-called 'echo DTMF.'	6–15 dB
<b>MinEnThr</b>	Minimum frame energy to count a frame as valid. The major usage of this threshold is to accommodate input data, which is not MSB scaled. If the input data is scaled down so that +3.17 dBm corresponds to 8159 amplitude (pure mu-law), for example, lower this threshold proportionally.  A note of caution:  The DTMF detector detects DTMF signals as low as -55–60 dBm, but it is not recommended that you stretch the acceptance range to such low values without a practical need. Imagine an office with two people in it, both using telephones. If one person in this office dials a handsfree telephone, which echoes the signal back as DTMF, this echo might be picked up by the other person's handset and possibly sent towards the DTMF detector, causing it to be reported as a normal dialed digit (by the second person).	-35–25 dBm
<b>SumEnThr</b>	Amount that cumulative energy is allowed to differ from raw from energy, in the following bands: 680–950Hz 1200–1650Hz 340–450 Hz If high talk-down or stutter dial tone immunity is required, then allow for a larger discrepancy.	1.5–5 dB
<b>2kUpThr</b>	Threshold by which signals above 2kHz shall be lower than signals below 2kHz.	10–20 dB
<b>VarThr</b>	Amount that the current frame energy for either low frequency or high frequency is allowed to differ from its average value.	1–3 dB
<b>FwdTwistThr</b>	As per the specification definition ([?]Fwd or Standard ...). This value has approximately 0.5dB of headroom, but allow for more headroom in very noisy conditions.	US, CA: 4dB
<b>RevTwistThr</b>	As per the specification definition. This value has approximately 0.5dB of headroom, but allow for more headroom in very noisy conditions.	US, CA: 8dB
<b>PartThr</b>	Amount that a low/high frequency can be lower than the respective band energy.	1.5–3 dB
<b>CleanThr</b>	Amount that the energy of maximum components in the band can be higher than any other components. Values above 13 dB are invalid.	6–13 dB
<b>MaxFreqDevThr</b>	Maximum allowed deviation of an instantaneous frame frequency from the standardized value, in a percentage (see the IDTMF_1DB notes). As a guideline, the acceptance margin in 'normal' conditions is:	1.0–3.0%

Parameter	Description	Recommended Range
<b>MinToneDuration</b>	<p>MaxFreqDevThr - 0.35% and the rejection margin is: MaxFreqDevThr + 0.15%.</p> <p>Note that if this parameter is set to greater than 2.5%, the margins are wider. Also, The EV_EARLY_value will grow if 'the gates are wide open.' A BellCore test shows that the number of EV_EARLY_ON events nearly doubles in a 0.5% increase of the MaxFreqDevThr parameter.</p> <p>Amount of time after the EV_EARLY_ON event is sent before the EV_START event is sent. The approximate mapping to DTMF duration is as follows: Rejected if duration &lt; sMinToneDuration*5 + 17ms. Accepted if duration &gt; sMinToneDuration*5 + 22ms</p>	2 (10 ms)
<b>MinPostSilenceDuration</b>	Amount of time that relative silence (NoiseThr) is present after the tone has ended. If echo DTMF is present, adjust both the NoiseThr and MinPostSilenceDuration parameters to ignore the echo.	3-6 (15-30 ms)
<b>AbortTimeout</b>	Number of 5 ms frames in which a signal is to be ignored if a faulty tone occurs.	3-6 (15-30 ms)

#### 4.1.4 DTMF Signal Measurements

DTMF detector provides following statistics of the incoming signal:

Parameter	Description	Precision
<b>LoEn</b>	Average energy of the maximum frequency component in low band (on or about 697, 770, 852, 941 Hz). The measurements are corrected to be precise if the actual frequency differs from the nominal value by <= 2%.	-0.7 dB
<b>HiEn</b>	Average energy of the maximum frequency component in high band (on or about 1209, 1336, 1477, 1633 Hz). The measurements are corrected to be precise if the actual frequency differs from the nominal value by <= 2%.	-0.7 dB
<b>LoFreqDev</b>	Average deviation of the frequency from the standard values mentioned above.	-0.5Hz
<b>HiFreqDev</b>	Average deviation of the frequency from the standard values mentioned above.	-1.5Hz

The DTMF detector keeps this data for MinPostSilenceDuration or AbortTimeout frames after the digit ends. If required, the user can retrieve this data beforehand. The data may be used to identify faulty equipment and adjust thresholds.

Data precision depends on noise and tone duration. If used in low-noise conditions with long digits (in excess of 200 ms), the energies are correct with precision of 0.5 dB, and offsets are correct with precision of approximately 0.2%. The numbers provided in the above table are for a case of AWGN 15dB SNR, 50 ms digits, and a frequency deviation of less than 2%.

The signal measurements are reported within IDTMF\_Status structure:

```
typedef struct IDTMF_Status {
    Int size; /* sizeof the whole parameter struct */
    IDTMF_tCfg *pCfg; /* in: ptr to cfg to update. */
    /* used if and only if CMD_CFG indicated */
    /* out: statistics */
    Int sLoEn;
    Int sHiEn;
    Int sLoFreqDev;
    Int sHiFreqDev;
} IDTMF_Status;
```

## 4.2 IALG Interface

TI's "Express DSP" compliant interface is fully supported. See relevant TI documentation.

## 4.3 Vendor specific API

### 4.3.1 Initialization

```
extern void DTMF_MIKET_init_db (void *pDb, IDTMF_tCfg *pCfg);
```

pDb shall refer to the user-allocated properly aligned memory block.  
pCfg shall refer to a valid configuration structure.

### 4.3.2 Control

```
extern void DTMF_MIKET_control  
(void *pDb, Int Cmd, IDTMF_Status *pStatus );
```

Cmd can be constructed by OR-ed flags:

```
#define IDTMF_CMD_OFF      (1)      // disable detector from running.  
                                  // function DTMF_process will return almost immediately.  
#define IDTMF_CMD_RESET  (2)      // reset database variables, data saving buffers, statistics, etc.  
                                  // preserves pointer to configuration data.  
                                  // If RESET is not or-ed with OFF, the detector starts running.  
#define IDTMF_CMD_CFG    (4)      // update pointer to configuration data to be used.  
                                  // pCfg in pStatus can point to the same configuration data  
                                  // for any number of DTMF detector instances.  
#define IDTMF_CMD_GET_STTS (8)     // request statistics structure to be filled
```

It is not recommended to apply OFF without RESET due to the obvious consequences of calling `_control(pDb, 0)`; afterwards.

Asynchronous calling `_control()` and `_process()` from different tasks is not recommended.

All other flags will be ignored.

### 4.3.3 Process

```
extern Int DTMF_MIKET_process(void *pDb, void *pSc, Int *pIn);
```

Returns report word: MSByte as event and LSByte as tone ID.

Event	Value	Meaning
IDTMF_EV_NONE	0	No changes happened this frame
IDTMF_EV_EARLY_ON	(1<<8)	That's probably a tone. This event is reported after 3.7...4.6 frames, if the frame is 5ms. It gives 18..23 ms of accumulation time. Given that last frame shall not be processed by a vocoder, and that minimal delay of 'heavy vocoders' (G.729) is 5ms, (7.5ms for G.723.1), only up to 13 ms of DTMF will 'leak' into bearer. This number is OK with ATM forum documents, prescribing that less than 20 ms of DTMF tone may be transmitted. No additional system delay to accommodate for DTMF relay required

IDTMF_EV_EARLY_OFF	(2<<8)	That's is not a tone. After EV_EARLY_ON was sent, DTMF detector may send EV_EARLY_OFF event to notify system that previous notification was false
IDTMF_EV_START	(3<<8)	The tone was OK for prescribed MinToneDuration. That's a tone for sure, we can say now.
IDTMF_EV_END	(4<<8)	The tone is over now. Clean and clear finish. The tone was followed by a relative 'silence' with the power level less than the threshold
IDTMF_EV_ABORT	(5<<8)	Something is wrong with this tone. It started Ok, went on ok for several frames, but something went wrong afterwards. As the result, it did not end properly

Normally, user shall get a sequence of  
EV\_EARLY\_ON,  
EV\_START,  
EV\_END.

LSByte of Report: Tone Id

```
#define IDTMF_TONE_0 (0)
#define IDTMF_TONE_1 (1)
#define IDTMF_TONE_2 (2)
#define IDTMF_TONE_3 (3)
#define IDTMF_TONE_4 (4)
#define IDTMF_TONE_5 (5)
#define IDTMF_TONE_6 (6)
#define IDTMF_TONE_7 (7)
#define IDTMF_TONE_8 (8)
#define IDTMF_TONE_9 (9)
#define IDTMF_TONE_A (10)
#define IDTMF_TONE_B (11)
#define IDTMF_TONE_C (12)
#define IDTMF_TONE_D (13)
#define IDTMF_TONE_STAR (14)
#define IDTMF_TONE_POUND (15)
```

Note that:

- pDb must point to initialized database.
- pSc must point to scratch pad. pSc shall point to DARAM if max speed is required, otherwise MIPS will almost double.
- pIn shall point to a frame (40|80 samples) of continuous data.
- If DTMF receiver was turned off, then pSc and pIn can point anywhere.

## 5 Specifications

### 5.1 General

Parameter	5 ms version	10 ms version
MIPS / Instance	0.36 MHz	0.242 MHz
Algorithm Memory (DARAM & SARAM), words	2.6 kW	2.6 kW
Instance Memory (SARAM), words	98 W	78 W
Mitel tests	Passes all	Passes all
BellCore test (hits, typical)	0–5	3–8
BellCore test ('early detection' hits, typical)	200–500	300–700

The limit of BellCore talk-off immunity test is 333. The DTMF detector performs much better than required.

### 5.2 Performance characterization

Although DTMF detector passes all relevant Bell-Core and Mitel tests with ease, there may be no warranty given that it will operate perfectly under all and any life circumstances. Note that DTMF detector operates with real-world data, it can be 'close to perfect', but it can not ever possibly be absolutely perfect.

Note that the performance of DTMF detector fully depends on the configuration parameter settings. If those are set inappropriate, the performance will be degraded or even DTMF detector may become dysfunctional. Ensure that a user understands the meaning of parameters and consequences of wrong settings before any changes applied.

There are numberless variations of test conditions, and only some of them may be of particular interest to a Licensee. The demo program provided is a bit-exact simulation of DTMF detector. It may be used to characterize the performance of DTMF detector in conditions of particular interest, if different from test cases provided.

#### 5.2.1 Default Configuration

The following table shows the default DTMF detector's settings.

Parameter	Value
FwdTwistThr	4.0 dB
RevTwistThr	8.0 dB
MinEnThr	-40.0 dBm
NoiseThr	10.25 dB
SumEnThr	2.75 dB
VarThr	2.0 dB
2kUpThr	11.0 dB
PartThr	2.0 dB
CleanThr	10.75 dB
MaxFreqDevThr	2.0 %
MinToneDuration	2
MinPostSilenceDuration	4
AbortTimeout	4

### 5.2.2 Test Case 1: Composite: Dial Tone, Noise and Twist

The test case described below shows a DTMF detector acceptance curve (when tone frequencies are varied), combined with AWGN and dial tone. This is a simulation of quite a bad residential line, having a high echo on the CO-generated dial tone, and twisted low-level DTMF from the CPE. This test was conducted as follows:

- Frequencies were varied in order of Test 3 of Mitel tape, from -4.0% to +4.0%, in 0.1% steps.
- 100 digits, with energy of -30 dBm per low band frequency and -36 dBm per high-band frequency, were generated for every step.
- Dial tone with energy of -22 dBm per frequency (nominal -16 dBm level and 6dB ERL) with frequencies 350 Hz and 440Hz, biased by 0.5% down, was added to the signal.
- AWGN with level of -48 dBm.
- Start, End, Abort, Early On, and Early Off events were recorded for every step and divided by 100 to obtain the acceptance ratio for every frequency step.

Note that dial tone level is 8dB higher than DTMF level, and noise is only 12 dB lower than the high-band component of DTMF.

The diagram shown below includes the following features:

- X-axis: frequency deviation in a percentage
- Y-axis: digit acceptance ratio (taken on the END event)

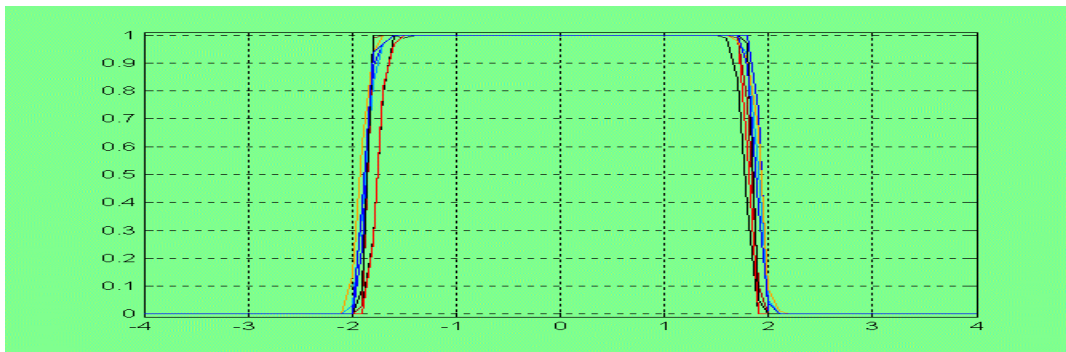


Figure 5.1. Cumulative acceptance curves

### 5.2.3 Test Case 2: Talk-Off Immunity and Threshold Variations

Max Freq Deviation Threshold, %	Early Detections	Starts	Ends
1.50	407	2	0
1.75	540	2	0
2.00	752	2	0
2.25	1006	5	0
2.50	1290	6	0
2.75	1601	12	0
3.0	2019	23	0

Noise Threshold, dB	Early Detections	Starts	Ends
5.0	1503	9	2
6.0	1262	6	1
7.0	1084	5	0
8.0	974	5	0
9.0	872	4	0

10.0	776	3	0
11.0	711	2	0
12.0	664	1	0

Clean Threshold, dB	Early Detections	Starts	Ends
6.0	752	12	0
7.0	752	9	0
8.0	752	9	0
9.0	752	6	0
10.0	752	4	0
11.0	752	2	0
12.0	752	0	0

Forward Twist Threshold, dB	Early Detections	Starts	Ends
3.0	730	2	0
4.0	752	2	0
5.0	780	2	0
6.0	802	2	0
7.0	811	2	0
8.0	823	2	0

Reverse Twist Threshold, dB	Early Detections	Starts	Ends
7.0	674	1	0
8.0	752	2	0
9.0	820	2	0
10.0	874	2	0
11.0	923	2	0
12.0	955	2	0

Sum Energy Threshold, dB	Early Detections	Starts	Ends
1.0	260	1	0
1.5	395	1	0
2.0	548	2	0
2.5	691	2	0
3.0	802	3	0
3.5	870	3	0
4.0	922	3	0

The dependence of the talk-off immunity on the thresholds for Variation, 2kUp, Part, and Minimum Energy is insignificant, if those thresholds have meaningful values.

#### 5.2.4 Test Case 3: Performance with AWGN

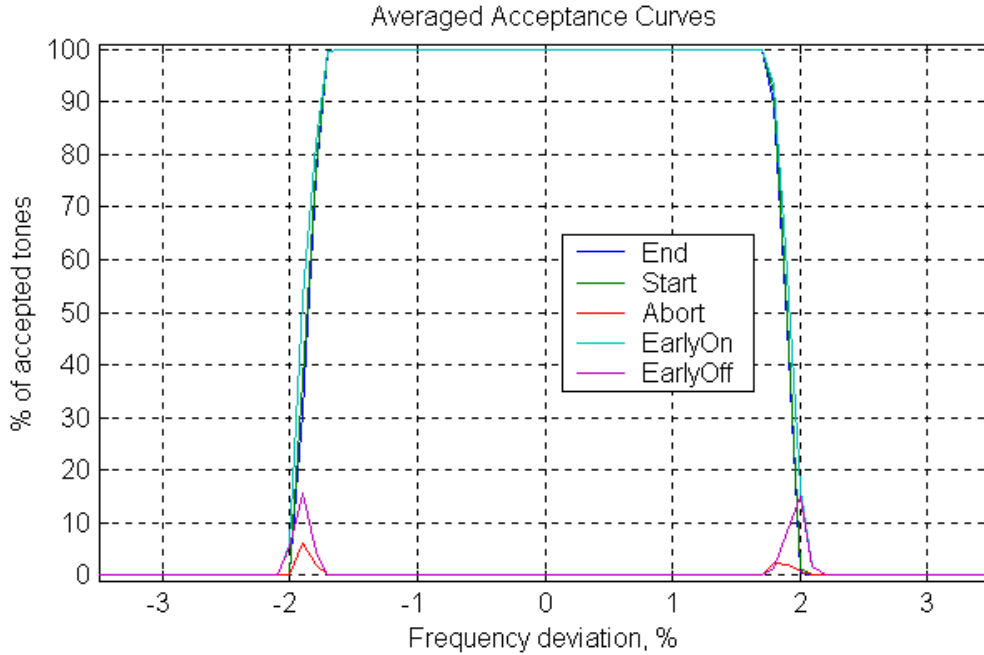


Figure 5.2 Cumulative acceptance curves for SNR of 24 dB.

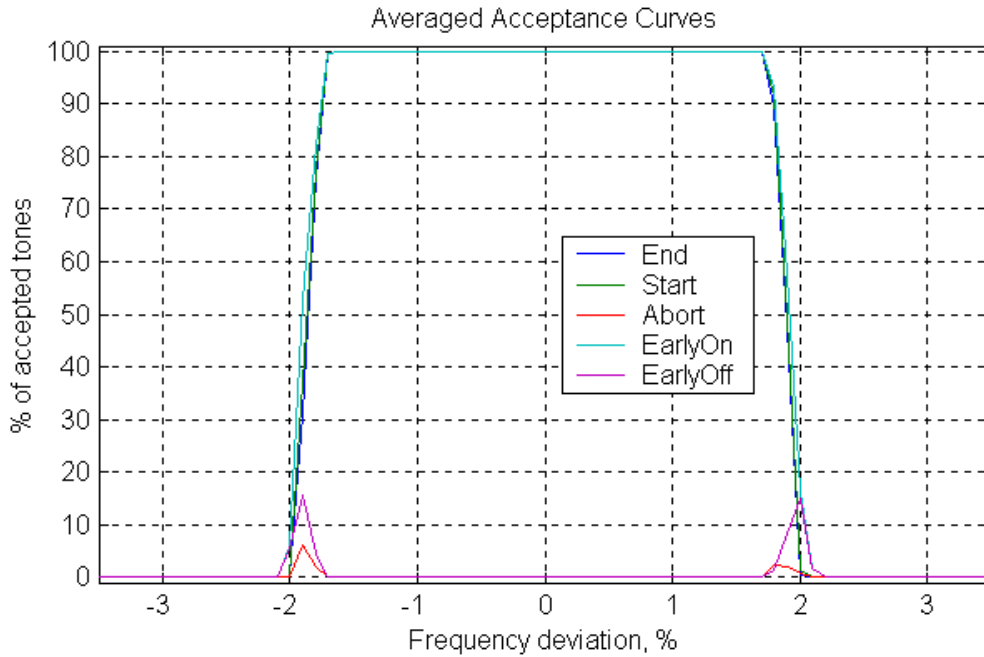


Figure 5.3 Cumulative acceptance curves for SNR of 18 dB.

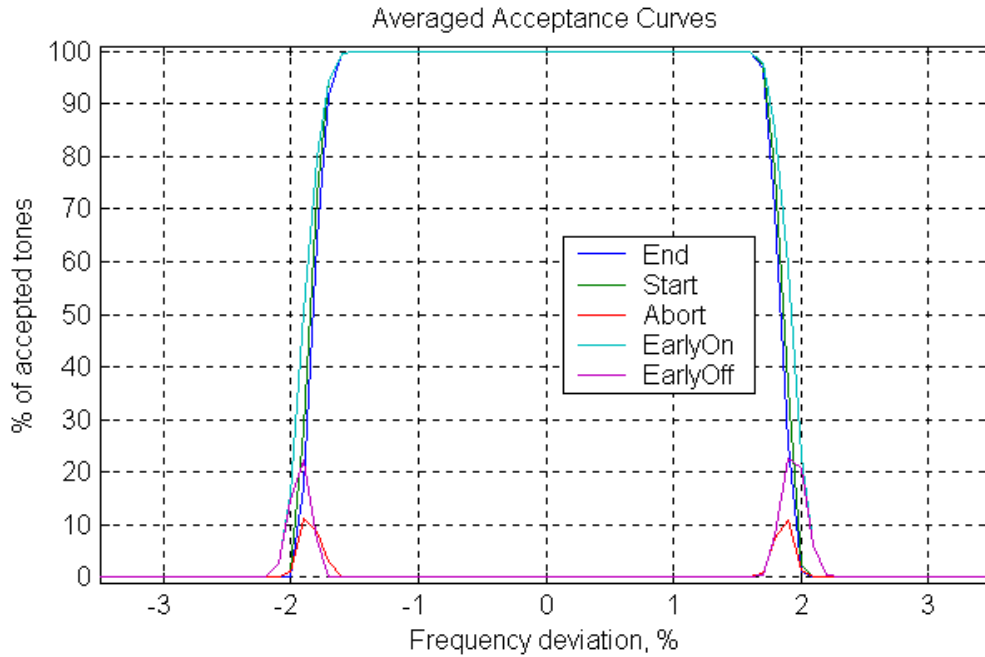


Figure 5.4 Cumulative acceptance curves for SNR of 15 dB.

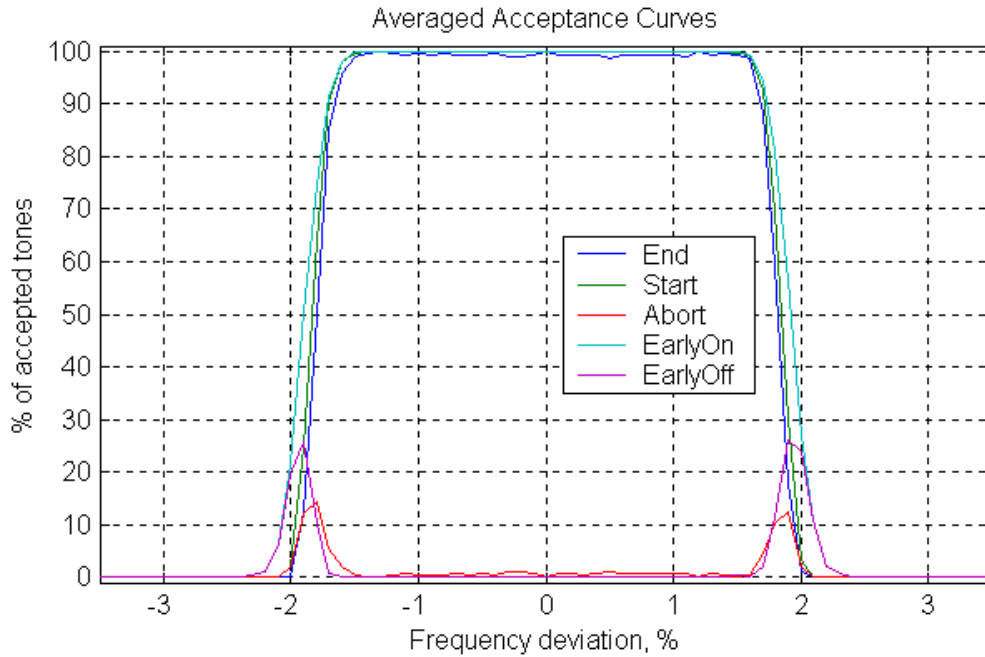


Figure 5.5 Cumulative acceptance curves for SNR of 12 dB.

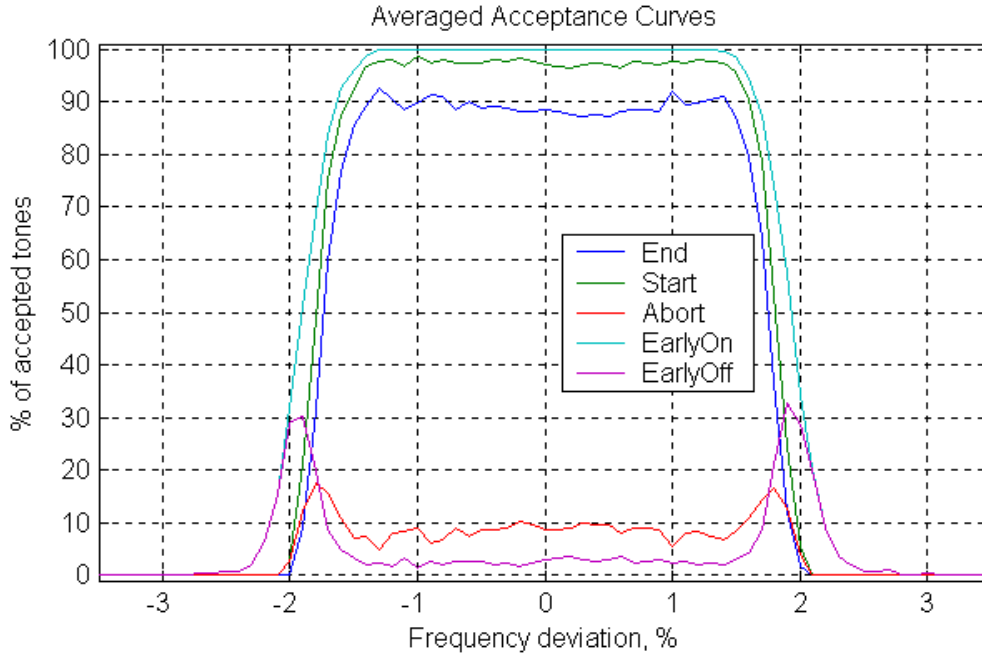


Figure 5.6 Cumulative acceptance curves for SNR of 8 dB.

### 5.2.5 Test Case 4: Twist sensitivity

The frequency of the tones is varied within 1%. SNR (AWGN) is 24 dB.

Forward Twist Threshold, dB	Early Detections, %	Starts, %	Ends, %
4.0	100.00	100.00	100.00
4.5	100.00	100.00	100.00
5.0	94.85	92.58	89.17
5.5	48.55	40.28	34.98
6.0	3.08	0.01	0.00
6.5	0.00	0.00	0.00

Reverse Twist Threshold, dB	Early Detections, %	Starts, %	Ends, %
6.0	100.00	100.00	100.00
7.0	99.96	99.96	99.95
7.5	54.23	49.70	49.37
8.0	3.83	0.32	0.09
8.5	0.00	0.00	0.00
9.0	0.00	0.00	0.00

### 5.2.6 Test Case 5: Early Detection Latency

The latency depends on the start of the DTMF tone is related to the 5 ms DTMF detection frame start. DTMF frequencies are varied within 1%, AWGN SNR of 24 dB.

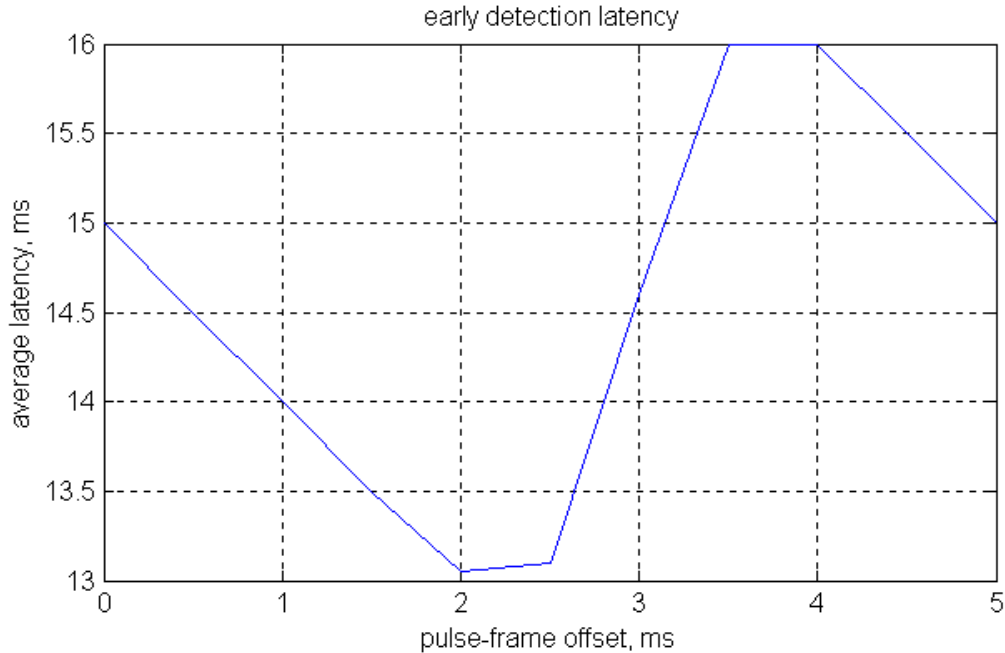


Figure 5.7. Early detection latency depends on the DTMF pulse start relative to the DTMF detector frame start. The 99% credibility interval is about +2ms. The latency for the events `_START` and `_END` will have the same correction curve.

### 5.2.7 Test Case 6: Dial Tone Immunity

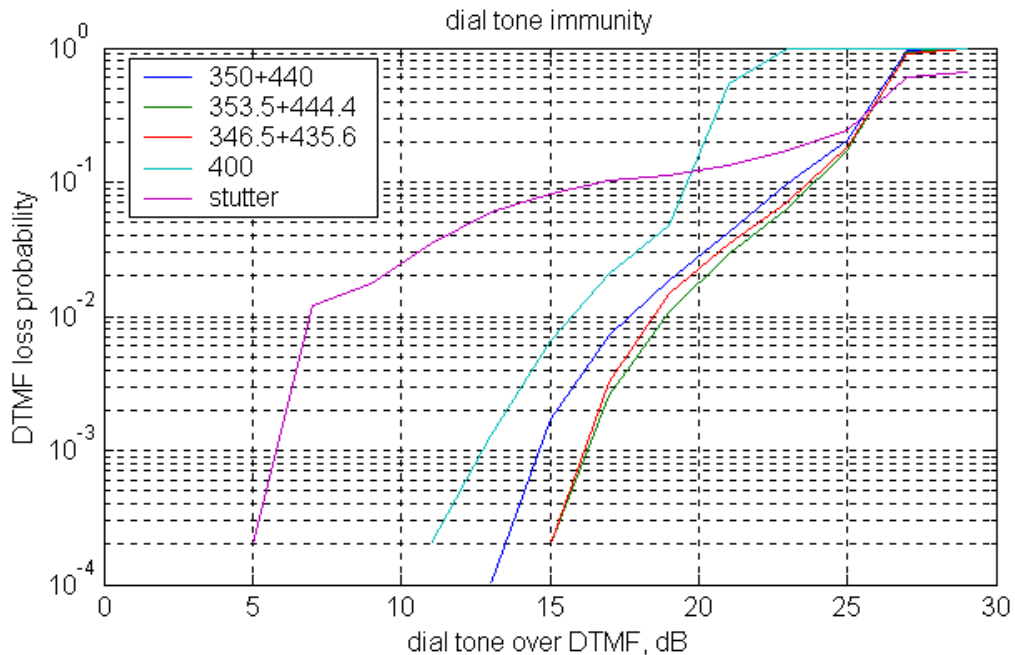


Figure 5.8. DTMF is pulsed 50ms on / 50 ms off, with frequencies within +/- 1% off nominal values. NA dial tone (350+440 Hz) frequencies are varied + or - 1% (see corresponding curves). NA stutter dial tone is pulsed 250 ms on, 255 ms off. AWGN SNR is 24 dB. DTMF loss is accounted for if there is no relevant `_END` event.

### 5.2.8 Test Case 7: Dynamic Range

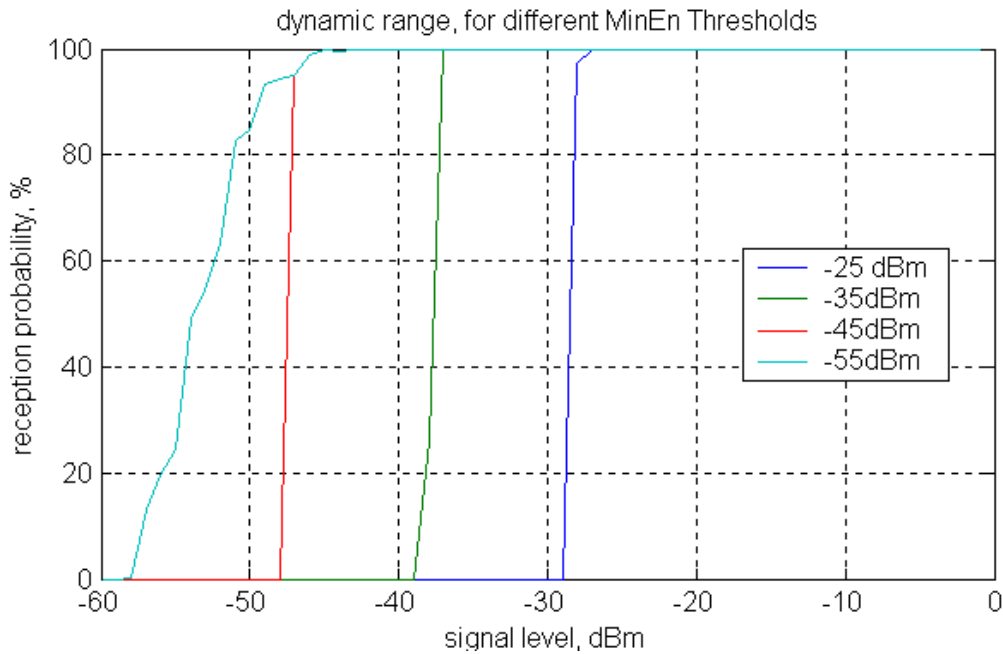


Figure 5.9. The probability of DTMF signal detection is given for the *\_END* event, depending on the MinEn threshold. AWGN SNR is 24 dB.

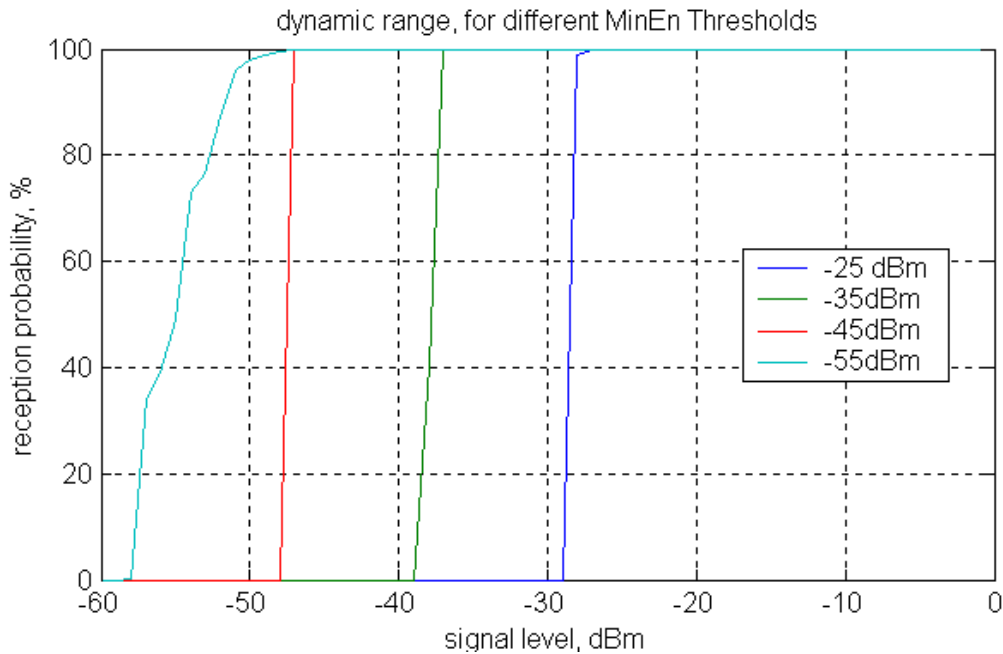


Figure 5.10. The probability of DTMF signal detection is given for the *\_START* event. AWGN SNR is 24 dB.

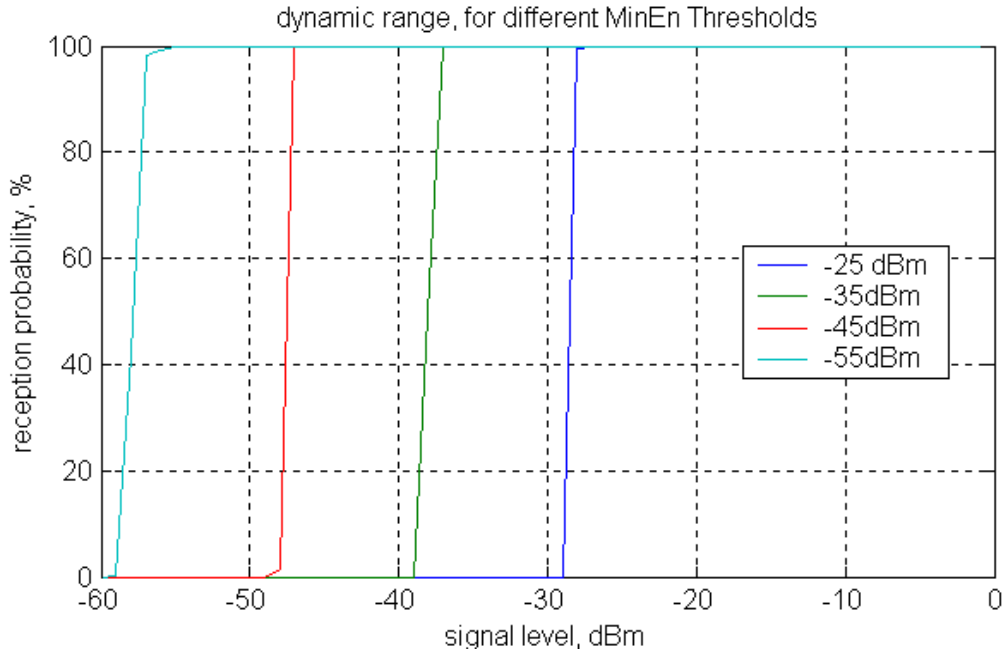


Figure 5.11. The probability of DTMF signal detection is given for the EARLY\_ON event. AWGN SNR is 24 dB.

### 5.2.9 Test Case 8: Tone Frequency Estimation Accuracy

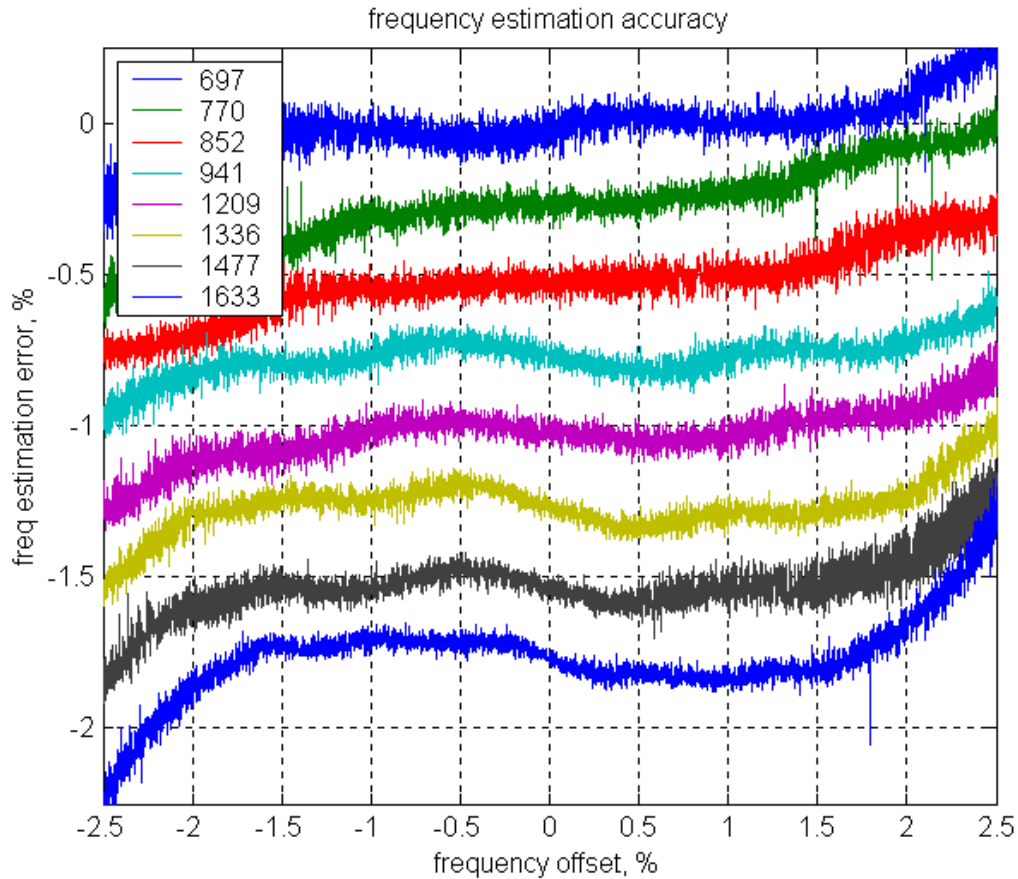


Figure 5.12. The frequency estimation errors given for the AWGN SNR of 15 dB for each frequency, spaced  $-0.25\%$  on the picture.

Within  $\pm 2.0\%$  range of each frequency variation off its nominal value, the estimation offset and standard deviations are measured as following (15 dB SNR):

Frequency	Offset, %	Standard deviation, %
697	-0.013	0.047
770	-0.027	0.102
852	-0.027	0.074
941	-0.022	0.040
1209	-0.025	0.051
1336	-0.017	0.044
1477	-0.034	0.048
1633	-0.018	0.055

The frequency estimation errors change with SNR, in quite good agreement with theoretical bounds for MLE errors.

### 5.2.10 Test Case 9: Low SNR Configuration and Performance.

If the DTMF detector has to operate in conditions of low SNR, as for Interactive Voice Response systems, or on noisy lines, the following configuration might be more appropriate:

Parameter	Value
FwdTwistThr	4.0 dB
RevTwistThr	8.0 dB
MinEnThr	-40.0 dBm
NoiseThr	9 dB
SumEnThr	2.75 dB
VarThr	3.0 dB
2kUpThr	8.0 dB
PartThr	2.0 dB
CleanThr	7.0 dB
MaxFreqDevThr	2.5 %
MinToneDuration	2
MinPostSilenceDuration	4
AbortTimeout	4

The talk-off immunity is:

Early\_On event: 1455  
Start event: 70  
End event: 0

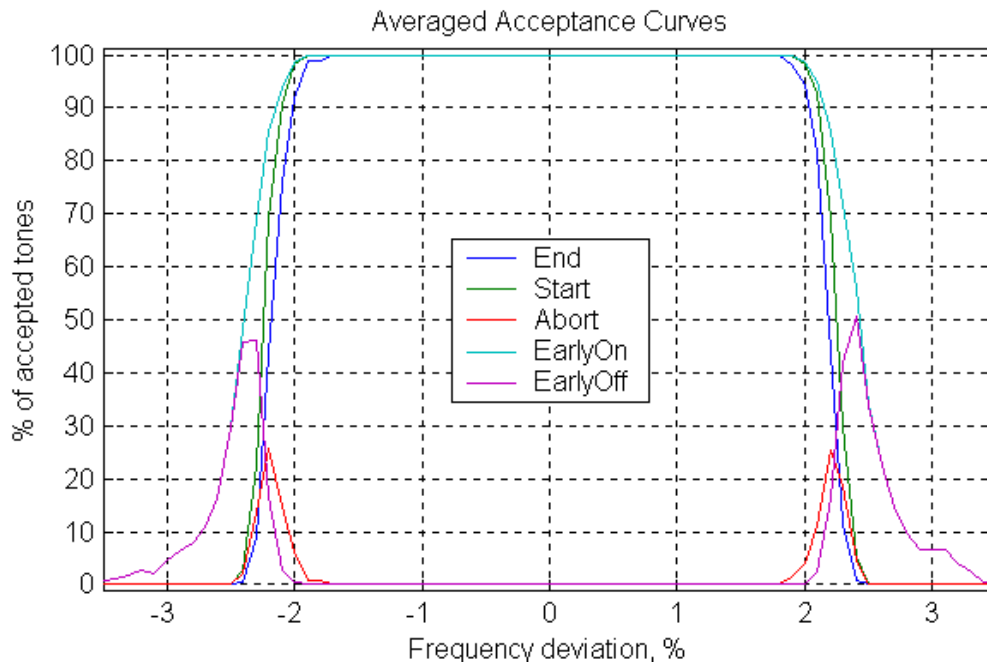


Figure 5.13. Acceptance curves for AWGN SNR of 9 dB.

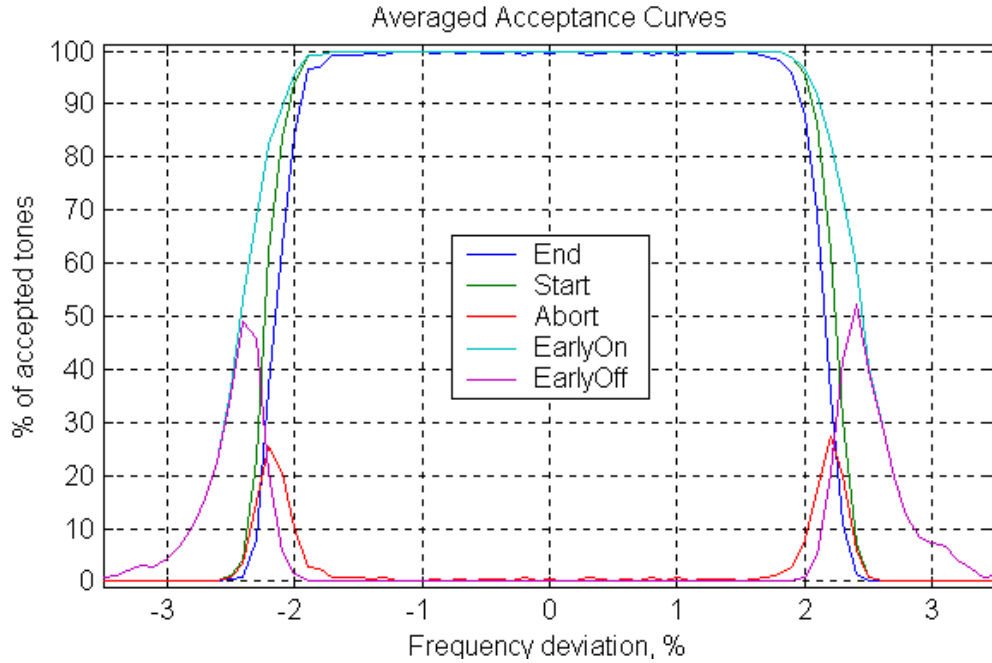


Figure 5.14. Acceptance curves for AWGN SNR of 7 dB.

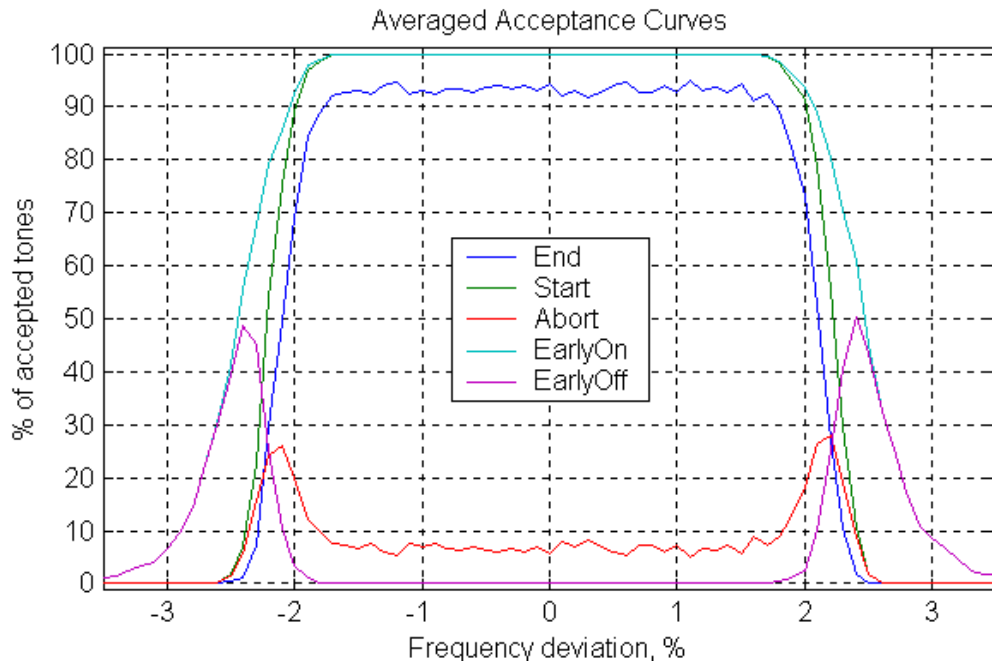


Figure 5.15. Acceptance Curves for AWGN SNR of 5 dB.

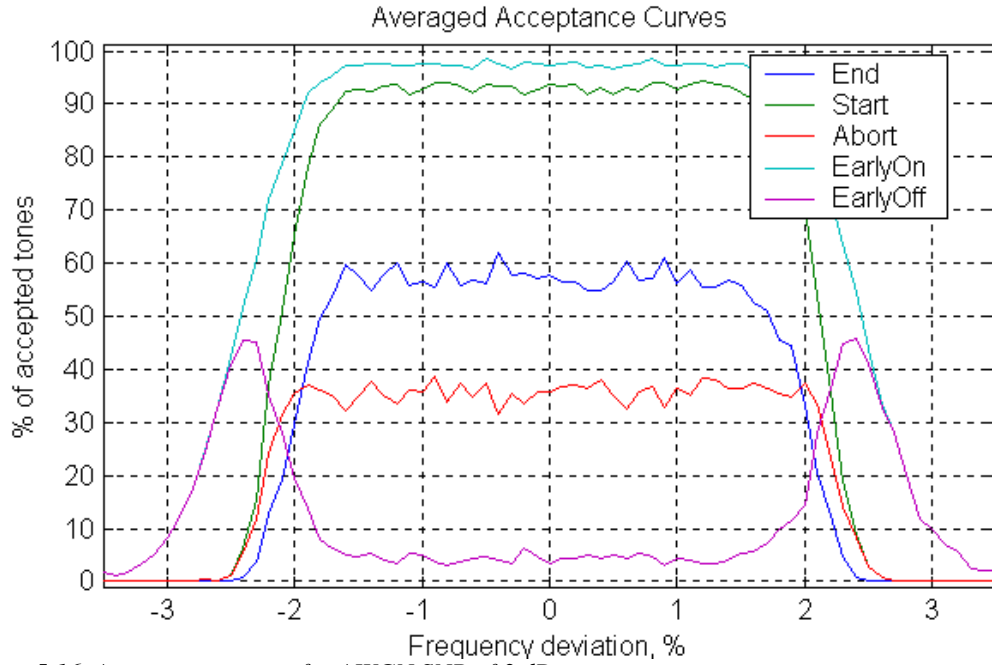


Figure 5.16. Acceptance curves for AWGN SNR of 3 dB.

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