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Personal Electronics for Law Enforcement
Solid State Recorders and Body Wires

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CONTENTS

1

1.   INTRODUCTION

This report summarizes the work performed by the Communications Networking Division (CND) of the Information and Telecommunications Technology Laboratory (ITTL) of Georgia Tech Research Institute (GTRI) under the "Personal Electronics for Law Enforcement" program. This program is being performed for the SPAWARSYSCEN Charleston. The report covers work done as part of a joint effort between GTRI, and Tektron, Inc. GTRI's efforts are focused on solid state audio recorders that could be used for law enforcement applications, and Tektron's efforts are focused on body wires for law enforcement applications.

This report includes information that is intended to assist the law enforcement community in the evaluation and purchase of audio recorders and body wires. It includes a market survey of commercially available audio recorder and body wire products, and it includes a brief review of key technologies used in these products. The first section of the report covers audio recorders, and the second section covers body wires. In addition, an appendix contains the results of a survey of law enforcement agencies that deals with the use of recorders and body wires for law enforcement applications.

2.   COMMERCIAL SOLID STATE AUDIO RECORDER PRODUCTS

Throughout this program, data has been collected on commercial-off-the-shelf (COTS) audio recorders that could be used for law enforcement applications. An incredible variety of recorders are available, including solid state audio recorders based on flash memory. Since solid state recorders have no moving parts, they can offer higher fidelity recordings than conventional cassette recorders. The solid state recorder does not suffer from background tape hiss or tape speed variations that degrade the fidelity of cassette recorders. For these reasons, special emphasis has been placed on solid state recorders in this study. For comparison with solid state recorders, data has also been collected on MP3 recorder/players, mini disc recorder/players, and digital audio tape recorder/players.

2.1   Overview of Commercial Audio Recorder Products

Table 2-1 presents a summary of the performance of various kinds of audio recorders. A solid state flash recorder (made by Olympus), a MP3 recorder (made by Creative Labs), a mini disc

recorder (made by Sony), and a microcassette recorder (made by Sony) are all compared in the table. This table does not include all the devices reviewed in the survey, but instead, includes devices that typify the performance of commercially available audio recorders that would be suitable for law enforcement applications. Data in the table is current as of July 2002.

Table 2-1. Audio Recorder Feature Summary

Recorder Type	Size	Record Time	Fidelity	Cost	Media Cost
Flash (Olympus DS2000)	4.3"x2"x0.65"	22hrsLP64MB 10hrsSP64MB 5hrsLP16MB 2hrsSP16MB	300-3kHz LP 300-5kHz SP DSS format	$175 with 32MB	$50 64MB $15 16MB Smartmedia card
MP3 (Creative Labs Nomad IIc)	3.7"x2.6"x0.9"	133min 32MB 66min 16MB	G721 ADPCM format	$114 with 64MB	$30 32MB $15 16MB Smartmedia card
Minidisc (Sony MZ-N707)	3.25"x3"x1.3"	5 hrs 1 MD	ATRAC3 format	$230	$2.50 minidisc
Digital Audio Tape (Sony TCD-D100)	1.125"x3.125"x 4.625"	120 min 90 min 60 min	20-22kHz	$750	$5.50 120min $4.50 90min $4.00 60min
Microcassette (Sony M850V)	4"x2.25"x0.88"	120 min 90 min 60 min	250-4000Hz	$65	$2.50 120min $1.50 90min microcassette

From the table, it is seen that all the devices are available in similar sizes, and all devices are capable of at least 2 hours of record time. The Olympus voice recorder and the MP3 player/recorder have similar frequency response to the microcassette. The ATRAC3 compression used by the minidisc recorder and the digital audio tape have the best bandwidth. In the cost category, the MP3 player/recorder is the next lowest cost after the microcassette. In the media cost category, the minidisc is the lowest after the microcassette.

2.1.1 Flash Audio Recorders

The flash based audio recorder is the main subject of this report. It offers a number of potential advantages: high fidelity, high reliability, small size, and reasonable cost (cost of both the recorder and the recording medium). Flash recorders have benefited from the proliferation of the use of flash memory for digital cameras and MP3 players over the past few years, and the cost of flash audio recorders has come down as a result. The material to follow describes the features of several representative commercially available flash audio recorder products.

The Olympus flash audio recorders are available in several models. The DS2000 is listed in the table. The DM-1 is also available for approximately the same cost, and has the added ability to play back MP3 music recordings. The DM-1 does not provide protection against accidental erasure. The Olympus DW-90 flash audio recorder costs approximately $90, has a non-removable 8MB flash memory, uses ADPCM compression, and can record from 22 (5.8kHz) to 90 (1.7kHz) minutes of audio. The DS2000 and DM-1 Olympus flash recorders use a file format called Digital Speech Standard (DSS). Files stored in this format occupy 12 times less memory space than uncompressed WAV files, while achieving roughly the same audio quality. Olympus flash voice recorders feature voice-activated recording that can be switched off. Olympus voice recorders use a standard USB interface to transfer data from the recorder to a PC. The Olympus recorders can record in monaural mode, but not stereo. Further information on these products may be obtained at the manufacturer's web site: http://www.olympusamerica.com/cpg_section/cpg_vr_digitalrecorders.asp.

The Panasonic RR-XR320 is another example of a flash audio recorder. The RR-XR320 is 1 7/8" x 3 9/16" x ½" in size, uses ADPCM recording and uses SD flash memory. It has a battery life of 11 hours when recording, and uses two AAA batteries. The MSRP of the RR-XR320 is $329, and street prices around $280 are common. This flash recorder uses a standard USB interface to transfer data from the recorder to a PC. It can record up to 150 minutes in "LP" mode with a 16MB SD flash memory card. High quality (HQ), standard play (SP), and long play (LP) recording modes are available. Further information on this product may be obtained from the manufacturer's web site: http://www.prodcat.panasonic.com/shop/NewDesign/ModelTemplate.asp?ModelID=13081.

The Sony ICD-MS515 is another audio recorder that uses flash memory (in the form of a memory stick). It is 1/3/8" x 4 1/8" x 23/32" in size, and uses 2 AAA batteries. The MSRP is $250. It can record for 10 hours in SP mode, and 12 hours in LP mode on a single set of batteries. It has voice activated recording, and uses a standard USB interface to transfer data

4

from the recorder to a PC. It can record 64 minutes in SP mode (using 16kHz sampling), and 150 minutes in LP mode (using 8kHz sampling). It features a built in omnidirectional microphone, and is a monaural recorder. Sony also makes a less expensive flash recorder (ICD-B25) without removable media for $100. Further information on these products may be obtained from the manufacturer's web site: http://www.sonystyle.com/electronics/prd.jsp?hierc=8627x8667x8668&catid=8668&pid=31982&type=p.

The DIALOG4/ORBAN SOUNTAINER MP3 player/recorder is another example of a compact audio recorder that uses flash memory in a multimedia card (MMC) format. Instead of ADPCM or DSS, it uses MP3 recording of audio. It is comparable in size and features to other recorders. This manufacturer prefers that detailed information on its recorder specifications should not be reproduced. So, for more information on this recorder, the reader is referred to the manufacturer's web site: http://www.dialog4.com/products/sountainer/supp_snt1.html.

Please note that solid state audio recorders from Adaptive Digital Systems (EAGLE/FBIRD8) are available for law enforcement purposes. For specifications on these products, please see http://www.adaptivedigitalsystems.com. A password, which may be obtained from the manufacturer, is required to access the specifications for these recorders.

Another manufacturer of solid state audio recorders for law enforcement purposes is Digital Audio Corporation. The product made by this corporation is the SSABR, which is described as a "state of the art, body worn digital recorder, specifically designed for collecting accurate, covert recordings." Details on this product may be found at http://www.dacaudio.com. A password, which may be obtained from the manufacturer, is required to access this data.

Yet another manufacturer of solid state audio recorders for law enforcement applications is Geonautics. This company makes a very small "Whisper" flash based recorder that is available in both mono and stereo configurations. Details on these products may be found at http://www.geonautics.com. A password, which may be obtained from the manufacturer, is required to access this data.

2.1.2 MP3 Player/Audio Recorders

Another class of commercial product with potential application for covert recording is the MP3 player. MP3, or MPEG Layer 3, is a lossy compression format that allows CD-quality music

recordings to be compressed into files significantly reduced in size to facilitate transfer over the internet and to and from PC's. MPEG formats accomplish this reduction in size partly by eliminating components of the recording that would be masked by the human hearing process based on a psychoacoustic model of hearing.

Many, but not all, MP3 players have voice recording capability in addition to MP3 playback capabilities. The MP3 playback frequency response is listed as a very high quality range of 20Hz to 20kHz. Unfortunately, the claimed frequency response of 20Hz – 20kHz applies only to the playback of MP3 files, not to recorded voice. The portable MP3 recorder/players reviewed to date use ADPCM for recording voice. The ADPCM implementations used have a bandwidth of 3 to 4kHz, which is much worse than the 20-20kHz achieved when playing back MP3 recordings. The ADPCM used in the voice recordings is based on 8 bit PCM samples, and has an upper limit of approximately 50dB for its signal to noise ratio.

The Creative Labs Nomad IIc MP3 player/recorder is a widely available MP3 player/recorder that can be used for recording audio onto flash memory (Smartmedia format flash). It is 3.7" x 2.6" x 0.9" in size, and uses 32kbps G721 (an ITU standard) ADPCM recording. It features a USB interface for transferring files to a PC. Further information on this device may be obtained from the manufacturer's web site: http://www.americas.creative.com/products/category.asp?category=2&maincategory=2.

The Sensory Science Rave MP2200 samples voice at 8kHz, and requires approximately 1MB of flash memory space for every 4 minutes of voice recording. So, for a built in flash memory of 64MB, this unit can store over 4 hours of voice. The specification of approximately 4 minutes of voice per 1MB indicates that some compression is being used to store the voice (approximately a 2:1 compression), which is consistent with 32kbps G721 ADPCM. Unfortunately, the Rave MP2200 does not store voice files on removable media, but only on the built in flash. Cost of the Rave MP2200 is approximately $200. More information on the Rave MP2200 may be obtained at the following URL: http://www.sonicblue.com/support/goVideo/downloads/MP2200manual.pdf.

A few of the MP3 recorder/players use 40 MB Iomega Clik! disks as the storage media, which are much cheaper than the removable flash cards. However, these disks are susceptible to shock and vibration, which could be a disadvantage for certain law enforcement applications.

2.1.3   Minidisc Player/Audio Recorders

6

A third interesting class of commercial products with potential for covert recording applications is the minidisc recorder/player. The minidisc is the most compact of the removable memory storage media, capable of storing approximately 160 MB of audio data on a disc that is 64 mm in diameter and approximately 1 mm thick. A typical minidisc device is not much bigger than the minidisc itself, with typical dimensions of 70 mm x 67.5 mm x 5 mm and being very similar in size to the MP3 player/recorders discussed above. Only Sharp and Sony currently produce minidisc recorder/players. These are the only COTS products reviewed so far that can make voice recordings in stereo and that can record voice using the full 44.1 kHz, 16 bit sampling that is a standard for audio CD's, allowing the full recording bandwidth for music or voice of 20 Hz to 20 kHz. However, to store audio with this large a bandwidth on the limited amount of memory space available, all minidiscs utilize a proprietary ATRAC3 compression scheme for the storage of data that is lossy, compressing the audio files by a ratio of approximately 4.83:1. Both Sharp and Sony have plans to produce higher density minidiscs and drives with a capacity of about 650 MB.

Pre-recorded minidiscs are fabricated using the same plastic-aluminum structure as CD's. The minidisc is read by focusing a laser on pits and valleys within the transparent polycarbonate substrate backed by a coating of aluminum that then reflects or disperses the beam to produce a series or 1's and 0's which can then be translated back into either the original data or sound. Recordable minidiscs have a pre-groove instead of the CD-type pits and valleys and a MO (magneto-optical) coating instead of the aluminum one. While recording, the laser focuses on the pre-groove and heats the MO recording layer at that point to its Curie point while a magnetic field from a head in contact with the other side of the disc aligns magnetic dipoles within the heated spot on the MO layer. During playback, the laser focuses on the pre-groove again, but at a lower power, allowing the measurement of changes in the polarization of the light reflected from the previously magnetized layer. All minidisc players have a dual function optical assembly that detects the disc type and switches between the measurement of reflectivity for pre-recorded minidiscs or polarization for recordable minidiscs. Sony claims recordable minidiscs can handle up to 1 million recordings. The minidiscs have a user table of contents that can be damaged if the minidisc is abused and render the minidisc unusable. Sony claims that data using magneto-optical technology can be stored for more than 30 years without loss or degradation. However, strong magnets placed directly against the minidisc can destroy data.

Minidiscs use a buffer memory that temporarily stores recorded audio, thereby helping to prevent vibrations from affecting either the recording onto or playback from the minidisc. However,

7

problems have been reported with recording when the minidisc recorder is subjected to shock and vibration, apparently due to the laser beam "skipping" and accidentally erasing previously recorded data on adjacent tracks. Therefore, it is recommended that the recorder should be immobile and not subjected to shock or vibration while recording. In addition, because of the 400-900 rpm rotation of the minidisc, all such devices produce a humming noise when recording or playing audio. Although this humming noise reportedly does not degrade the recording or playback process, it could possibly interfere with the covert recording process. Because the laser beam must heat the disk while recording, the minidisc device is the only portable recording device that consumes more power during recording than during playback. And even during playback, the devices still consume 50-100% more power than any other class of recording device. Until recently, none of the minidisc recorder/players have had a convenient means to connect to a PC to allow the rapid transfer of files.

The Sony MZ-N707 minidisc recorder offers some of the advantages of flash recorders. It records onto a digital medium (the minidisc), and is not subject to the tape hiss that is present in cassettes. The minidisc must spin to work, so, unlike flash recorders, there are moving parts inside the minidisc recorder. The size of the MN-N707 is 3 ¼" x 3" x 1 1/8". It comes with a rechargeable battery, and records in a high fidelity ATRAC3 format. An external microphone is needed to record audio, since the unit does not come with a built in microphone. It uses Sony's ATRAC3 compression technique for storing audio (and music). The ATRAC3 compression technique achieves relatively high fidelity, but it is not lossless. Another model, the MZ-N1, is available for $350, and it is somewhat smaller in size: 3" x 2 7/8" x ½". The MZ-N1 features a higher capacity battery than the MZ-N707. Further information on these devices may be found at the following URL: http://www.sonystyle.com/electronics/ssctypg.jsp?hierc=8627x8650x8647&catid=8647.

2.1.4   Digital Audio Tape (DAT) Recorders

One DAT device, a TCD-D100 produced by Sony, is included in this survey for comparison purposes. This DAT recorder, which lists for $900, can provide up to 4 hours of stereo recording on two AA batteries. This DAT device can sample at 48kHz, 44.1kHz or 32kHz, and uses 16 bit quantization. At a 48kHz sample rate, it has a 20-22 kHz frequency response (within 1 dB), which is greater than the full range of human hearing (20-20kHz). At 44.1 kHz and 32 kHz sample rates, it has a 20-14.5 kHz frequency response (within 1 dB). The signal to noise ratio is 87dB, and the total harmonic distortion is 0.008%. The wow and flutter is less then 0.001 percent. All of these specifications are excellent, and stack up favorably against the solid state

recorders. DAT tapes are available providing 60 minute and 120 minute recording times. A digital output is available, but it is not known how easily a digitized recording could be transferred to a PC using this output. Recordings can be transferred to a PC in real-time using the Line In/Line Out connections. A microphone must be purchased separately. Further information on this device may be found at the following URL: http://www.sonystyle.com/home/item.jsp?hierc=9687&catid=8662&itemid=591&telesale=null& hidden=null&cps=null&type=s. A related product, the NT-2 Digital Micro Recorder is also available from Sony. The NT-2 is smaller than the TCD-D100, but it has slightly worse specifications. Further information on the NT-2 may be found at: http://www.sonystyle.com/home/item.jsp?hierc=9687&catid=8668&itemid=563&telesale=null& hidden=null&cps=null&type=s.

2.1.4   Microcassette Recorders

Microcassette and cassette recorders are used by numerous law enforcement agencies. These devices typically have relatively poor frequency response (250 Hz to 4 kHz for microcassettes, somewhat better for cassettes), have relatively high wow and flutter (due to the mechanical tape transport), and have poor signal to noise and distortion characteristics when compared to solid state recorders. Often they have voice activated recording and automatic level control that cannot be turned off. In many law enforcement applications, it is an advantage to be able to turn off voice activated recording and automatic level control. Some advantages of the microcassette and cassette recorder are they are small, they are low cost, they use batteries that are widely available, and they use cassettes that are widely available.

The Sony M850V is a typical microcassette recorder. It has a frequency response of 250 Hz to 4 kHz, which is well below the human hearing range of 20 Hz to 20 kHz. It has an 11 hour battery life, and uses 2 AA batteries. It is relatively small, with dimensions of 4" x 2.25" x 7/8". It has voice operated recording and automatic level control. This recorder is monaural, and has its own built in microphone and speaker. It features two recording speeds. The frequency response quoted is for the higher recording speed. Further information on this recorder may be found at the following URL: http://www.sonystyle.com/home/item.jsp?hierc=9687x8667x8671&catid=&itemid=34003.

2.2   Commercial Audio Recorder Issues

One issue (potential shortcoming for law enforcement use) with the flash recorders and MP3 player/recorders is the bandwidth achieved in the audio recording. For the recorders with LP (long play) mode, relatively low sampling rates are used in recording the data (longer recordings can be made in a given memory size when lower sample rates are used). Unfortunately, the Nyquist sampling criteria limits the bandwidth of the recording to one-half of the sampling frequency. Thus, the audio bandwidths for recordings made in the LP mode are relatively low. A typical sample rate for LP recording is 8kHz, and, by the Nyquist sampling criterion, the resulting audio bandwidth must be less than 4kHz (typically 3kHz). This audio quality is approximately the same as telephone voice quality. The 32kbps ADPCM recording scheme used by the MP3 player/recorder in Table 2-1 also achieves a telephone voice quality bandwidth of approximately 3kHz. A somewhat better frequency response is achieved by the SP (standard play) mode of the flash recorders. Sampling rates used in this mode are 12kHz, and the resulting audio bandwidth must be less than 6kHz (typically 5kHz). Although these bandwidths are adequate for speech recognition purposes, they do not compare favorably to the human hearing bandwidth of approximately 20 kHz, and they may not be suitable for all law enforcement applications.

Another issue with flash recorders and MP3 player/recorders is the loss in fidelity caused by compression schemes used by the recorders. The recorders attempt to maximize recording time for the available memory by compressing the sampled audio using proprietary compression schemes. The higher compression algorithms (greater than 4:1), which conserve the most memory space, turn out to be lossy; that is, they degrade the fidelity of the recording. The 32kbps ITU G.711 ADPCM compression used by the MP3 player/recorder in Table 2-1 is a relatively low loss algorithm. The minidisc recorder uses ATRAC3 compression, which has a compression ratio of 4.8:1. Manufacturers that use the MP3 compression standard have a compression ratio of greater than 10:1. The DSS (digital speech standard) compression scheme used by the Olympus DS2000 stores 120 minutes (7200 sec) of highest quality voice in 16Mbytes of flash. A rough calculation of the seconds of uncompressed speech that can be stored in 16Mbytes is:

16M bytes x 1sec/12k samples x 1 sample/1 byte = 1333 sec

Comparing the compressed seconds of storage to the uncompressed seconds of storage gives a compression ratio of 5.4 for DSS. Although playback quality may not be affected significantly by lossy compression schemes for most purposes, one of the concerns in using nonlinear

compression for law enforcement recordings is the legal question that might be raised over the accuracy and faithfulness of the recording.

A third issue with the commercial audio recorders has to do with dynamic range and signal to noise ratio of the recorded audio. The 8 bits per sample used in these recorders provides for a signal to noise ratio that will not exceed 50dB (i.e., $6.02n + 1.76$). This signal to noise ratio may not be adequate for all law enforcement applications. For example, if we try to recover low level audio that is more than 50dB below some high level audio, it will be buried in noise.

Another issue in using commercial audio recorders for law enforcement purposes is whether or not to use automatic gain control. It would be desirable to be able to defeat the automatic gain control feature for some applications.

Another issue is whether or not to use voice activated recording. Voice activated recording conserves room on the recording medium, and it extends battery life by shutting down the process of recording the audio onto the storage medium when no audio is present. However, a threshold must be set to activate the voice recording. If the threshold is set too high, some weaker signals that are desirable evidence may be missed. So, for recorders that do have voice activation, it is desirable to be able to turn off the voice activation.

Another issue is storage of original evidence at a reasonable price. Unfortunately, there is often a significant delay of months or even years before a case comes to trial. It would be costly to have to remove the recorder from use while waiting on a trial. And downloading the original recording to a PC may not be accepted as original evidence. The original flash memory module used to record the audio may be the only recording accepted as original evidence. The ability to have removable flash memory that can be saved as original evidence is a desirable feature of flash based audio recorders. Using removable flash memory allows the recorder to continue to be used (with a new flash module) while the original evidence flash module is saved for trail.

3.0 CURRENT AND PROJECTED STATE OF THE ART IN SOLID STATE RECORDER TECHNOLOGY AREAS

3.1 Solid State Recorder Block Diagram

Figure 3-1 shows a block diagram of a typical solid state voice recorder. Starting at the top left of the figure, the audio signal is received by one or more microphones. Next, an amplifier/filter

increases the voltage of the signal from the microphone to the correct level for the input to the analog to digital converter (ADC). Some filtering (removal) of unwanted signals may also occur in this block. The ADC converts the analog input signal to a digital word that is fed to audio compression hardware. The audio compression hardware (for example, a DSP) implements an audio compression algorithm, which reduces the number of bytes needed to store the audio signal. The resulting compressed audio bytes are saved in flash memory. The flash memory is removable, for convenient storage of evidence. The user interface is implemented by the DSP sensing the switch positions on the recorder.
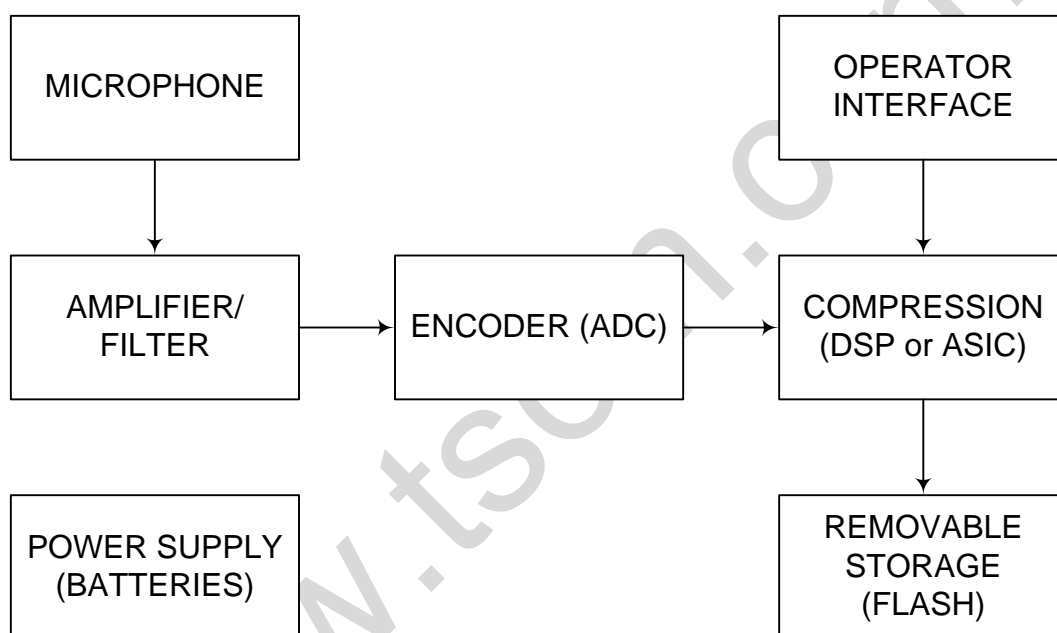
Figure 3-1. Solid state voice recorder block diagram.

Playback of the audio signal may be provided in a number of ways. Commercial items, such as the SanDisk ImageMate USB CompactFlash/SmartMedia media reader (cost is approximately $30), may be used to transfer the compressed audio from the flash memory card to a PC. The PC would run software to decompress the audio, and play back the result on the PC sound system. The flash recorder manufacturer could provide custom audio decompression PC software, or, if a standard compression/decompression algorithm is used, a third party could provide the audio decompression PC software.

In the design of the flash based audio recorder, the resulting product is only as good as the worst individual part. The various parts of the recorder will be discussed in the following sections.

3.2   Microphones

Two major classes of microphones that could be used in flash based audio recorders are dynamic and electret condenser. The dynamic microphone transforms sound into an electrical signal by the movement of a diaphragm with a coil of wire attached to it. This coil of wire is located close to a magnet, and when the diaphragm/coil moves in the magnetic field, a current is produced in the coil. This current corresponds to the audio signal that moves the diaphragm.

Electret condenser microphones operate somewhat differently. The diaphragm and the "back plate" in an electret condenser microphone form two surfaces of a capacitor. Either the diaphragm or the back plate contains a permanently charged electret material. When the diaphragm moves, the distance between the surfaces of the capacitor changes, inducing a current that corresponds to the audio input. Since the electret condenser microphone diaphragm does not have a coil attached to it, it can be fairly light when compared to the dynamic microphone. As a result, the electret condenser microphone generally has better sensitivity and high frequency response than a dynamic microphone.

One characteristic of a microphone is its directivity, which is its sensitivity to sound arriving from different directions. A microphone that picks up sound equally well in all directions has an "omnidirectional" pattern. A microphone that is more sensitive to sounds in front of the microphone that behind the microphone is "unidirectional" (cardioid). A microphone that is sensitive to sounds in front and behind, but not to the sides, is "bi-directional" (noise canceling).

One typical electret condenser microphone is the Panasonic WM-61 series. This back electret condenser omnidirectional microphone has a frequency response from 20 to 20kHz, a signal to noise ratio of better than 62dB, and a sensitivity of –35dB (0dB = 1V/Pascal). The WM-61 has a low power consumption of 0.5 mA at 2V.

For law enforcement applications, the superior frequency response and sensitivity of the electret condenser microphone is preferred over the dynamic microphone. For monophonic recordings, an omnidirectional microphone is preferred. For stereo applications, either cardioid or omnidirectional pattern microphones may be used.

3.3   Delta Sigma Analog to Digital Converters

In solid state audio recorders, audio signals must be converted from the analog domain to the digital domain so they can be stored in a digital format in flash memory. This function is performed by a high quality analog to digital converter (ADC).   One type of ADC that is particularly well suited to this task is the delta sigma ADC. The delta sigma ADC samples the input waveform at a much higher rate than is normally required (often 128X oversampling is seen in these devices). Oversampling distributes the quantization noise all the way up to the sampling frequency, thereby reducing the amount of quantization noise in the audio band. The delta sigma ADC also uses a noise shaping filter. This noise shaping filter effectively moves quantization noise from the audio band to higher frequencies. The delta sigma converter then uses a digital filter to remove the higher frequencies (and quantization noise), and retain the audio frequencies. The resulting digitized signal from the delta sigma converter has very little quantization noise, and is highly accurate representation of the input analog waveform.

Delta sigma converters are typically inexpensive, have low power requirements (suitable for a battery operated voice recorder), and are highly accurate. One device, the CS5333, converts two inputs (for stereo operation), provides 24 bits of output, requires only 11mW, and costs less than $5. As seen in the specifications of the CS5333, the current generation of delta sigma analog to digital converter has more than enough performance to meet law enforcement needs of high dynamic range and full audio bandwidth, and it is reasonably priced.

Delta sigma ADCs and digital to analog converters (DACs) are used in audio sound cards for PCs.   The demand for these products may roughly be expected to follow the demand for PCs in the future. Which is to say, the high demand for delta sigma converters (both digital to analog and analog to digital) in computer audio sound systems makes the continued availability of these devices highly likely.

3.4   Audio Compression Algorithms

Audio compression algorithms are used in flash based audio recorders to reduce the amount of flash memory required to record a specified duration of audio. If 20kHz audio is sampled at the Nyquist rate of 40kHz, then, in the absence of compression, each second of audio requires 40,000 audio samples to be stored in flash memory. A compression algorithm that achieves a compression ratio of 4:1 would reduce the flash memory storage requirements from 40,000 down

to 10,000. A fixed amount of flash memory can store 4 times as much audio when a 4:1 compression algorithm is used.

Audio compression algorithms may be divided into two categories: lossless and lossy. When recordings made using lossless compression are played back, the original signal is reproduced exactly, and no compression artifacts are present. When recordings made using lossy compression are played back, the original signal is not exactly reproduced, but a slightly degraded version of the original signal is reproduced. Lossless audio compression schemes typically achieve compression ratios in the range of 1.5:1 to 3:1. Lossy audio compression schemes typically achieve compression ratios in the range of 4:1 to 12:1 and higher (Windows Media Audio claims 24:1).

The state of the art lossless audio compression process can be divided into three stages: framing, decorrelation, and entropy coding. Framing divides the audio signal into equal duration frames. Optimum duration frames appear to be in the range of 13 to 26ms. Audio signals exhibit a high degree of autocorrelation; that is, the current sample can be predicted from previous samples. To take advantage of this characteristic, the original signal is decorrelated (and the correlation characteristic is remembered). It is more efficient to store the correlation characteristics in the encoded waveform than it is to store the audio samples. Several techniques are available for performing decorrelation: coding with linear prediction, coding with approximation, and transform coding. Once the correlation in the waveform has been removed, the remaining decorrelated waveform must be encoded. Entropy coding is used for this purpose. Some standard entropy coding methods include: Huffman coding, run length coding, and Rice coding. Some representative state of the art lossless audio encoders include the following:

- AudioPAK (integer)
- MUSICompress (fixed point)
- Sonarc (fixed point)
- Shorten (floating point)
- Ogg Squish (floating point)
- LTAC (lossless transform audio compression - floating point)
- Waveform Archiver (floating point)

The objective of the AudioPAK algorithm is to reduce the complexity of implementing lossless audio compression while maintaining compression ratios that are comparable to the more complex lossless audio compression algorithms. Notice that the AudioPAK uses integer

15

operations, while the other algorithms mentioned use fixed point or floating point operations. Much of the material in this section has been derived from: <u>Optimization of Digital Audio for Internet Transmission</u> by Mat Hans – Georgia Institute of Technology PhD thesis, 1998 (http://users.ece.gatech.edu/~hans/). This thesis describes the AudioPAK algorithm.

Another lossless compression technique worth mentioning is bit plane encoding. With this technique, a particular bit of each PCM sample is encoded over a frame of samples. This process is repeated until all bits have been encoded. This technique expects that the most significant bits of audio PCM samples will not change very often, and can be efficiently run length encoded. The least significant bit is expected to change frequently, and can use Huffman entropy encoding.

Before leaving the subject of lossless audio compression, it is interesting that lossless audio compression can be achieved by using the PKzip (Winzip) algorithm that is so familiar to today's computer users.   Unfortunately, the PKzip algorithm does not achieve very good compression ratios for audio files (typically 1.1:1). One reference that discusses PKzip (Winzip) performance relative to other lossless audio compression techniques, and lossless audio compression performance in general is "Digital Audio Gets an Audition, Part 1 Lossless Compression," EDN, January 4, 2001.

A number of lossy audio compression techniques are available. We will briefly describe two here: MP3 and ATRAC. These two compression techniques are used in MP3 players and mini disc recorders respectively.

Although the MP3 players do not use MP3 compression to record audio (they typically use 32kbps ADPCM instead), the compression scheme is one dominant form of lossy audio compression that is used today (the Soundtainer product mentioned above uses MP3 to record audio). MP3 stands for MPEG Audio Layer 3 (as opposed to the lower compression MPEG Audio Layers 1 and 2). MP3 can achieve compression ratios of 10:1 to 14:1 with a bandwidth of over 15kHz. One method the MP3 algorithm uses to reduce the amount of information to be encoded (thereby compressing the size of the audio file) is to omit audio that is not perceptible to humans. One example is called frequency masking. In this situation a loud sound present in one frequency band masks softer sounds present in an adjacent frequency band. In this instance, humans will not notice a difference when the soft sounds are completely removed. Similarly, MP3 observes a minimum audio threshold, and will not record sounds below a certain level at certain frequencies (2 to 5kHz), since these will not be perceptible to humans. MP3 "borrows"

16

from a "reservoir of bytes" to encode more complex audio, and "replenishes" the reservoir during less complex audio passages. MP3 uses a discrete cosine transform that has 384 coefficients to decorrelate the audio signal. It then throws away data that would not be noticed by the listener. Finally, MP3 uses Huffman entropy encoding, once the audio that will not be encoded has been subtracted from the signal.

ATRAC (Adaptive Transform Acoustic Coding) is the compression technique used in mini disc recorders. It typically achieves a 5:1 compression ration on CD audio, and, like MP3, it uses a psychoacoustic model of human hearing to determine what sounds may be subtracted form the original signal without being detected by human hearing. ATRAC divides the audio frequency band into 3 subbands (0-5.5kHz, 5.5-11kHz, and 11-22kHz) using Quadrature Mirror Filters (QMFs – prevents aliasing when reconstructing). A discrete cosine transform is performed on each subband using an adaptive block length (long or short). Long block lengths provide superior frequency resolution, but are subject to "pre echo" during "attack" portions of the audio signal. Short block lengths are used to prevent pre echo. and transforms these subbands into the frequency domain. Signals that would be masked by psychoacoustic effects are subtracted from the resulting frequency domain coefficients, and the coefficients are encoded into BFUs (block floating units). (reference: ATRAC: Adaptive Transform Acoustic Coding for Mini Disc, Tsutsui et al, 93rd Audio Engineering Society Convention, Oct 1-4, 1992.) A newer version of ATRAC called is ATRAC3 is now available.

Both MP3 and ATRAC (as well as many other lossy audio compression algorithms – AC3 for example) use a psychoacoustic model of human hearing to remove signals that would not be perceived by humans as a method of reducing the amount of audio that must be saved (as a method of compressing audio). For law enforcement applications, this practice may not be acceptable in some situations. For example, if a soft sound contains information needed by law enforcement personnel, and a loud sound "masks" it, the soft sound will be removed from the encoded audio when either MP3 or ATRAC is used. For this reason, audio compression algorithms that rely on the psychoacoustic model of human hearing to delete audio signals are not recommended for law enforcement applications (at least not all law enforcement applications).

Other lossy audio compression algorithms include:

- AAC (Advanced Audio Coder www.aac-audio.com)
- ATELP (www.softsound.com/ATELP.html)

- DTS (www.dtsonline.com)
- ePAC (www.lucent.com/ldr)
- Indeo (www.ligos.com)
- Ogg Vorbis (www.vorbis.com)
- Qdesign (www.qdesign.com)
- Real Audio (www.real.com)
- TAC (kk-research.hypermart.net)
- TwinVQ (sound.splab.ecl.ntt.co.jp/twinvq-e)
- Windows Media Audio (www.microsoft.com/windows/windowsmedia)

A reference that gives an overview of these algorithms and their performance is "Digital Audio Gets an Audition, Part 2 Lossy Compression," EDN, January 18, 2001.

One further audio compression algorithm worth mentioning is apt-X 4:1. This algorithm uses ADPCM to achieve a 4:1 compression ratio, with very little loss in audio quality. This algorithm uses four frequency subbands, but does not rely on psychoacoustic models of human hearing to throw away audio information that is not perceptible to humans. More information may be found on this technique at http://www.aptx.com.

3.5   Audio Compression Hardware

Audio compression algorithms are implemented on audio compression hardware, which includes Digital Signal Processors (DSPs) and custom Application Specific Integrated Circuits (ASICs). DSPs are specialized computer chips that have features that facilitate the implementation of audio compression algorithms. Like any computer, DSPs may be reprogrammed to perform different functions. ASICs are not reprogrammable. The Field Programmable Gate Array (FPGA) may be used to develop algorithms that are then readily transferred into an ASIC.

Highly capable, low cost DSPs have become available in the past few years. For example, the TMS320VC5402 DSP from Texas Instruments is capable of 100 million instructions per second (MIPS), and has 16K words of on chip RAM, and 4K words of on chip ROM. The cost of this part is approximately $6 in quantities of 1000. A part specifically designed for low power consumption, the TMS320VC5502, is also becoming available. It has 32K words of on chip RAM and 4K words of on chip ROM, and features 400 MIPS performance. The 5502 part will sell for approximately $10 in quantities of 1000. Both the 5402 and the 5502 are fixed point processors.

18

The trends toward lower core voltages, smaller geometry devices, and higher processing capabilities in DSPs and ASICs can only benefit flash based audio recorders. The current capabilities of DSPs like the 5502 are more than adequate for implementing fixed point and integer lossless audio compression algorithms for flash based audio recorders.

3.6   Flash Memory

Flash memory is used to store the compressed audio in the solid state recorder. Flash memory is used in cell phones, digital cameras and MP3 players. The cost of the flash memory is the dominant cost of the recorder. A 16kHz Obviously, any reductions in the cost of flash will reduce the cost of the flash based audio recorder.

In mid 1998, an Intel 28F640J5 8 M byte flash part cost $65. Today (2002) a comparable part, the 28F640J3A, costs $13.42, a reduction of nearly 5 times. Perhaps even more important than the cost of the individual flash chips is the cost of removable flash media. Driven by the proliferation of digital cameras and MP3 players, the cost of removable flash media has dropped significantly in the past years. Today's street prices for SanDisk flash products are as follows:

CompactFlash 1 G Byte: $631
CompactFlash 512 M Byte: $269
CompactFlash 256 M Byte: $115 (if 1000 units are purchased, the cost is $102)
CompactFlash 128 M Byte: $63
Memory Stick 128 M Byte: $70
Secure Digital 256 M Byte: $161
MultiMedia 64 M Byte: $52
Ultra CompactFlash 128 M Byte: $77

Flash memory provides a method of storing digital audio data that is non volatile; that is, data stored in flash memory is not lost when the power is turned off to the device. Flash memory may be NAND based or NOR based. NAND based technology is considered well suited for high capacity data storage applications, such as storage of audio files. Current flash memory for file storage often uses 2 bit per cell storage, an improvement over the older single bit per cell flash technology.

Flash memory that uses 0.25, 0.16, and 0.13 micron semiconductor process technology is currently available, and smaller process technology is being planned. Parts that operate on 3V and 1.8V are commonplace, and lower voltages are being planned. These developments are expected to reduce cost for given storage size devices, and lower power consumption, which would both benefit flash based audio recorders. SanDisk is expecting prices to drop approximately 30% over the coming year.

3.7 Batteries

Batteries for mobile electronic applications such as digital cameras and MP3 players may be divided into two groups: rechargeable and non-rechargeable. Within the rechargeable group, the most popular technologies today are: nickel metal hydride (NiMH) and lithium ion (Li-Ion). In the non-rechargeable group, the most popular technologies are the alkaline and carbon zinc batteries.

Nickel metal hydride batteries require recharging more often than lithium ion batteries, but they cost less than lithium ion batteries. Lithium ion batteries provide a better energy density than nickel metal hydride batteries. An energy density figure of 75 Watt hours per kilogram is provided by nickel metal hydride batteries, versus 135 Watt hours per kilogram for lithium ion batteries. The output voltage of lithium ion batteries is typically higher (3.0V) than the output voltage of nickel metal hydride batteries (1.2V). When compared to nickel cadmium rechargeable batteries, both nickel metal hydride and lithium ion batteries offer the advantage of not having any memory effect. (http://www.nec-tokin.net/now/english/product/me/chisiki/li3.html).

The alkaline battery in a AA size can provide 3000mAh at 1.5V, and an energy density of 140 Watt hours per kilogram. In comparison, a AA carbon zinc battery in AA size can provide only 950mAh at 1.5V and an energy density of 50 Watt hours per kilogram.

Alkaline and carbon zinc batteries have sloping discharge curves. That is, as the battery is discharged, the voltage goes down over time. In contrast, the nickel metal hydride and lithium ion batteries have flatter discharge curves. When these batteries are discharged, the voltage does not go down over time as much as with the alkaline and carbon zinc batteries.

The popularity of laptop computers, cell phones, cordless phones, digital cameras, MP3 players, and personal digital assistants has spurred the demand for rechargeable batteries. In 2000, the

market for rechargeable batteries was \$1.75 billion. This market is projected to grow to \$2.19 billion by 2006. The technology that will account for most of the battery demand in 2005 is the Lithium Ion. Lithium Ion batteries are expected to grow from 25% of the battery market in 1999 to 55% of the battery market in 2005. (source: http://www.eetimes.com/myf00/ao_batt.html)

One emerging battery technology is Lithium Ion Polymer. This battery technology has the potential to greatly increase the energy density when compared to current Lithium Ion products. Another Lithium Ion emerging battery technology replaces the cobalt in the battery with a different cathode material. The problem with cobalt is that it requires protection circuits inside the battery to prevent thermal runaway when the battery is being charged. One company, Valence Technology, claims that using Saphion for the cathode will reduce the cost of lithium ion batteries (http://www.valence.com/saphion.asp).

The development of a low cost, widely available, lithium ion polymer battery with high energy densities could reduce the size required for batteries in the flash based audio recorder. A reduced size recorder has obvious advantages for law enforcement purposes. It is uncertain when lithium ion polymer batteries will reach this stage of development.

4.0   PROJECTED COMMERCIAL SOLID STATE RECORDER PRODUCTS
(IN 2 YEARS)

Solid state recorder products are in a state of rapid development and improvement, with models constantly being discontinued and replaced by newer, improved models. Since this program and evaluation of devices began, many of the models initially in the product matrix (see Appendix A) had to be dropped and replaced by more current models.   The trend has been toward recorders/MP3 players with larger memory capacity and lower costs. This trend is expected to continue.

But the demand for higher bandwidth portable voice recorders has not been seen yet. There is a strong demand for MP3 players (i.e., there are lots of MP3 player products being sold), which feature voice recorders as a secondary feature. And there is a strong demand for voice recorders used for business dictation applications. But these kinds of voice recorders do not need to have high bandwidth, and no mass market commercial voice recorder has bandwidths up to 16 kHz or higher that would be useful for law enforcement applications.

As removable flash memory cards continue to increase in memory storage space and decrease in cost, the solid-state MP3 recorder/players may evolve to take advantage of this storage space and become true music recorders as opposed to simply voice recorders. Commercial motivation may encourage these recorder/players to take advantage of the 44.1 kHz sampling frequencies currently used to decompress and playback the MP3 files and begin recording audio files in stereo with MP3 compression as opposed to simply decompression. These devices could then compete very favorably with the minidisc recorder/players in the marketplace, being slightly smaller in size and less power hungry. But the market is not seen for MP3 recorders. Most consumers are not interested in recording their own music, via a microphone. Instead, they are interested in transferring music tracks from CDs or from the web to their PC and then storing them on MP3 players. And even if a MP3 recorder did evolve, the lossy compression used in MP3 is not always suitable for law enforcement purposes.

The market for high fidelity portable audio recorders would seem to be pretty much the same as the market for portable digital audio tape (DAT) recorders. Today, this market is a low volume, relatively high cost niche. For example, the Sony TCD-D100 DAT recorder lists for $900 and it was difficult to find a dealer that sells this device. It may be possible that DAT will evolve into a flash based product, but the demand to make it a low cost item sold in large quantities is not seen.

5.0   AUDIO RECORDER CONCLUSIONS

Desired characteristics of audio recorders for law enforcement purposes are as follows:
- wide and flat frequency response (20-20kHz)
- high signal to noise ratio and dynamic range
- low wow and flutter
- low harmonic distortion
- lossless compression
- defeatable automatic level control
- defeatable voice activated recording
- stereophonic recording
- combined microphone response that is omnidirectional
- record times of at least 60 minutes, with 120 minutes and higher available
- removable media
- low cost media

- wide availability of media
- wide availability of batteries
- small size
- low cost

Large volumes are projected in MP3 player recorders, and, to a lesser extent, in solid state voice recorders. But large volume (low cost) products (current and projected) fall short in several key areas:

Current and projected future commercial flash recorder products weaknesses:
1. lossy compression
2. poor frequency response
3. poor dynamic range and signal to noise ratio

Current and projected MP3 player voice recorder combination product weaknesses:
1. poor frequency response
2. poor dynamic range and signal to noise ratio

Current and projected mini disc weaknesses:
1. lossy compression
2. Susceptibility to shock and vibration

Many commercial products use automatic level control and voice activated recording features that cannot be defeated. The ability to defeat these features is desirable for many law enforcement applications.

To record 120 minutes of uncompressed 16 bit PCM audio with a bandwidth of 16 kHz (sampling at 32 kHz) requires 460 Mbytes of flash. State of the art lossless compression algorithms achieve 2:1 to 3:1 compression ratios. So, when lossless compression is used, only 230 Mbytes of flash are needed (instead of 460). Four years ago, the cost of flash was approximately $8 per Mbyte, making the cost of the flash memory required in the above situation about $1200. Today, the cost of flash has dropped to less than $0.50 per Mbyte (street price). A 256 Mbyte CompactFlash plug in card can be purchased for $128 or less. So the falling cost of flash has improved the affordability of the flash based audio recorder.

$128 is a significant amount of money to spend on a recording medium that may be put on the shelf while waiting on a trial. But it is much better than the $1200 or so it would have cost 4 years ago. And the expected future improvements in the cost of flash memory will reduce this $128 to an even lower figure.

Falling prices and larger sizes of flash memory make the solid state recorder a very practical idea. Improved wow and flutter, increased immunity from shock and vibration, and the elimination of tape hiss (improved signal to noise ratio) result from the use of flash. But widespread commercial demand for improved frequency response, high dynamic range, high signal to noise small solid state recorders is not seen. Instead, business uses of recorders for dictation purposes, which do not require high bandwidth, high dynamic range, and high signal to noise ratios are seen as the driving factor in future solid state audio recording products. There is a market for high bandwidth, high dynamic range, high signal to noise ratio playback products (MP3 players), but only for playback, not for recording.

To get the characteristics of lossless compression, high bandwidth, high dynamic range, and high signal to noise ratio, law enforcement personnel must continue to purchase specialty products such as the FBIRD or the SSABR. No projected future high volume commercial product will provide all the capabilities of these devices.

It would be possible to make a product that would satisfy today's law enforcement demands at a reasonable cost. Appendix B shows the major components of such a product, and that the cost would be around $140 in parts (excluding circuit boards and cases, and assuming parts are purchased in quantities of 1000). The major cost factor in this product is the flash memory, which accounts for $102 out of the $140 total component cost. The product would feature lossless compression (2:1), a bandwidth of 16kHz, a signal to noise ratio approaching 90 dB, and over 120 minutes of record time. It would feature removable flash media, and not have automatic level control or voice activated recording. It would have a size of approximately 9 square inches.

6.0 COMMERCIAL BODY WIRE PRODUCTS

Law enforcement agencies utilize body-wires for officer security, and to obtain evidence. Audio quality, transmitted power, and price vary with different systems. Typically, the transmission range can be between 30 and more than 3,000 feet depending on the environment and the quality of the equipment. In addition, there are many different frequencies utilized for transmission.

The purpose of the body wire is to transmit audio in the form of a radio signal to be received, understood and/or recorded at a remote location. The person wearing the body wire can be moving and turning in locations that range from outside to inside a building and from ground level to many stories up. While the transmitter is often mobile, the receiver is generally in one location. In the case of vehicle audio surveillance, both the transmitter and receiver are in motion, but the transmission distance is generally constant.

The transmitter may be required to cover thousands of feet or a few yards. The different environments of the signal propagation path will cause different attenuation levels: the signal will become attenuated and the range, therefore, reduced if it is required to travel through numerous buildings. Noise conditions, present at the time the audio signal is recorded, will vary from those of an outdoor, urban environment (which has many possible levels of background noise) to that of a quiet indoor room.

Throughout this program, data has been collected on body wires that could be used for law enforcement applications under the conditions described above. A wide variety of body wires are available. These products are discussed in the following sections.

6.1 Overview of Body Wire Products

Table 6-1 presents a summary of the performance of various kinds of body wires. Three types of body wires cover the majority of body wire products: Narrow Band FM (NBFM), Digital, and Spread Spectrum Digital. Actual representative products were evaluated to fill in this table, but the band names of the products have been omitted. Strengths and weaknesses of each body wire category are listed in the table.

Table 6-1. Body Wire Types and Feature Comparison

Feature	NBFM	Digital	Digital Spread Spectrum
Voice quality	LOW	VERY HIGH	MODERATE to VERY HIGH
Transmission Range	HIGH	MODERATE	LOW to MODERATE
Battery Lifetime	MODERATE	MODERATE	LOW to MODERATE
Physical Disguise	HIGH	MODERATE	LOW to MODERATE
Electronic Security	LOW	MODERATE	HIGH

6.1.1   Narrow Band FM Body Wires

Narrow band frequency modulation (FM) body wire transmitters use the output signal of the microphone to frequency modulate a radio frequency (carrier) to form the transmitted waveform. This modulation technique is an analog modulation technique, since the microphone signal was not first digitized before modulating the carrier.

Frequency modulation leaves the amplitude of the carrier constant, but changes the "instantaneous" frequency of the carrier in accordance with the amplitude of the signal from the microphone. Loud audio signals from the microphone correspond to relatively large changes in the frequency of the carrier. Soft audio signals from the microphone correspond to relatively small changes in the frequency of the carrier. Since FM signals use the frequency instead of the amplitude of the carrier to carry the audio from the microphone, they are inherently immune to amplitude noise.

Commercial FM radio stations use a form of FM called wideband FM. In this case, the frequency of the carrier can change up to 75kHz due to loud audio from the microphone. In contrast, body wires use narrowband FM. For narrowband FM the frequency deviation caused by loud audio from the microphone is much less than the wideband case. In the case of narrowband FM, the frequency of the carrier can change up to 5 or 7kHz.

6.1.2 Digital Body Wires

A digital body wire passes the output of the microphone through an analog to digital converter (ADC), the output of which is a series of 1's and 0's referred to as bits of digital data. This digital data then modulates a radio frequency (carrier) using a digital modulation technique.

One example of a digital modulation technique that is commonly used in digital body wires is phase shift keying (PSK). In the case of phase shift keying, the phase of the carrier is changed according to whether a 1 or a 0 data bit is being transmitted. For example, transmitting a 0 data bit could correspond to no change in the phase of the carrier, and transmitting a 1 could correspond to a 180 degree change in the phase of the carrier. There are many variations on this simple example of PSK that could be used in body wires. Other digital modulation techniques, such as differential phase shift keying (DPSK), frequency shift keying (FSK), or amplitude shift keying (ASK), are also possible to use in digital body wires. A comparison of some of the more common digital modulation techniques is shown in the table below.

Scheme	Bandwidth needed (r_b is the bit rate)	Bit error rate performance (S/N for 10^{-4} bit error)	Equipment complexity
ASK	Moderate (approx $2r_b$)	Poor (18.33 dB)	Minor
FSK	High ($>2r_b$)	Fair (15.33 dB)	Minor
PSK	Moderate (approx $2r_b$)	Best (8.45 dB)	Major
DPSK	Moderate (approx $2r_b$)	Good (9.3 dB)	Moderate

Table 6-1. Comparison of Binary Digital Modulation Schemes (from <u>Digital and Analog Communication Systems</u> by K. Shanmugam)

As seen in the table, the PSK and DPSK techniques achieve the best bit error rate performance. Digital modulation schemes with better bit error rate performance will require less transmit power to communicate over a fixed range, which is beneficial for battery life. Or, equivalently, a system with better bit error rate performance can communicate over a longer range using a fixed transmit power.

The "S/N" term in the table refers to signal to noise ratio. This term is the ratio of the received signal power to the received noise power. This ratio is often measured in decibels (dB). The formula for S/N in dB is 10 x LOG_{10} (signal power/noise power), where LOG_{10} is a base 10

logarithm. In the table, notice that the ASK modulation takes a S/N of 18.33 dB to achieve a bit error rate of 10^{-4}. In comparison, PSK modulation only takes a S/N of 8.45 dB to achieve the same bit error rate. So it takes a lower signal power for PSK than for ASK to achieve a given bit error rate performance, which is an advantage of using PSK modulation instead of ASK modulation.

6.1.3 Digital Spread Spectrum Body Wires

The digital spread spectrum body wire passes the output of the microphone through an analog to digital converter. Next, the resulting digital data is further encoded by another (higher rate) sequence of 1's and 0's referred to as a PN (Pseudorandom Noise) sequence. The resulting high rate digital sequence is then used to modulate the carrier. This form of spread spectrum is referred to as "direct sequence" spread spectrum.

The rate of the PN sequence is referred to as the "chip rate," and the rate of data bits from the microphone's analog to digital converter is referred to as the data rate (r_b). The processing gain of the spread spectrum signal is approximately the ratio of the chip rate to the data rate.

The effect of encoding the microphone digital data with the higher rate PN sequence is to spread the energy of the transmitted signal over a wider band of frequencies than would otherwise be used. One advantage of spreading the frequencies in this manner is that the signal becomes harder to detect than non spread signals.

When a direct sequence spread spectrum signal is received, the first operation is to "despread" the received signal. This dispreading operation is performed by multiplying a time aligned version of the PN sequence with the PN sequence in the received waveform. As a result of this despreading, any narrowband interferers present in the received signal will be spread out, and less energy from the interferer will be passed into the data demodulation process. The amount of rejection of the narrowband interferers corresponds to the processing gain of the signal. So a second advantage of a digital spread spectrum body wire is its ability to reject narrowband interference.

One further possible advantage of direct sequence spread spectrum worth mentioning is its secure communication capability. It is necessary to know the transmitter's PN sequence in order to despread the signal and listen to the audio. Using a long PN sequence, and keeping the PN sequence confidential can achieve secure communications.

In addition to direct sequence spread spectrum, another form of spread spectrum, called frequency hopping, is also possible. Instead of using a PN sequence, frequency hopping spread spectrum systems change the carrier frequency of the transmitted waveform periodically. Frequency hopping spread spectrum systems have similar advantages to direct sequence spread spectrum systems.

6.2 Body Wire Issues For Law Enforcement

When considering acquiring or using a body wire system, the user should be cognizant of six performance features:

1. Voice Quality of the Received Audio
2. Transmission Range
3. Battery Lifetime
4. Physical Disguise
5. Electronic Security
6. Cost

Understanding the role played by these six attributes will prove to be an asset in determining the suitability of a body wire system under consideration. Each of the features 1 through 5 is discussed in this section. The most significant manufacturer specifications for each feature are provided along with the associated Figures of Merit.

6.2.1 Voice Quality of the Received Audio

Voice quality is a very important aspect of body wire performance. Poor voice quality could prevent the listener from hearing words in a conversation, from understanding words in a conversation, or it could prevent the listener from determining which person was speaking in a conversation. Any of these problems could place the agent in danger, or prevent the collection of information needed to solve a case.

Voice Quality can be assessed primarily from specifications of AUDIO BANDWIDTH, AUDIO DYNAMIC RANGE and, if available, AUDIO SIGNAL TO NOISE RATIO.

AUDIO BANDWIDTH (audio frequency response) is an important measure of voice quality. A body wire system with the highest audio bandwidth performance will cover the entire range of frequencies that can be heard by the human ear (20 Hz to 20 kHz). A high quality music Compact Disc (CD) has a frequency response of 20 Hz to 20 kHz. A body wire system that only covers the frequency response of a telephone, which is 400 Hz to 4 kHz, would be considered to have relatively poor audio bandwidth performance. There is clearly a difference between the sound quality of a voice on a telephone and a music CD. Table 6-2 below presents useful information for evaluating the specifications and performance of body wire audio bandwidth.

Quality	Lower Frequency	Upper Frequency
Telephone quality	400 Hz	4 kHz
Adequate	200 Hz	6 kHz
Good	100 Hz	8 kHz
Very Good	100 Hz	12 kHz
Excellent	50 Hz	16 kHz
Superb	< 50 Hz	> 16 kHz

Table 6-2. Figure of Merit for Body Wire Audio Bandwidth

AUDIO DYNAMIC RANGE (ADR) is another important measure of voice quality. ADR is a measure of the systems ability to handle loud and soft sounds. It is the ratio of the loudest undistorted signal that the system can handle compared to its internal noise. Ideally, a body wire system with the best ADR would have the same dynamic range as the human ear, which has a dynamic range of over 120 dB. However, contemporary digital recording techniques can only achieve a dynamic range of about 90 dB.

Table 6-3 shows relative volume levels for different sounds. The levels in dB are relative to the threshold of hearing that is taken to be 0dB. From the table, it is seen that the audio dynamic range necessary to capture audio from whispers to a shout must be greater than 72 dB (90-18 dB).

Sound	Level (dB)
Threshold of hearing	0
Quiet Whisper at 5 feet	18
Quiet Office	55

Average Conversational Speech	70
Shout	90
Subway	102
Threshold of Painful Sound	130

Table 6-3. Relative Audio Dynamic Range – Sound Pressure Level

From the above table, figures of merit may be determined for body wire systems. Table 6-4 shows the figures of merit for the audio dynamic range of a body wire system.

Rating	Audio Dynamic Range (dB)
Poor	< 40
Moderate	60
Excellent	> 80

Table 6-4. Figure of Merit for Audio Dynamic Range

Many body wire radio systems do not have sufficient dynamic range to handle full audio sound levels. Some may be limited to as little as 30-40 dB.   When audio dynamic range is limited, sometimes automatic gain control (AGC) is used to position the dynamic range window in the most advantageous place to accurately pick up the most critical audio levels. The AGC shifting of the dynamic range window may produce undesirable audio artifacts. A carefully crafted AGC will reduce or eliminate these artifacts.

AUDIO SIGNAL TO NOISE RATIO (SNR) is another important measure of voice quality. SNR is the ratio of the audio signal power to the noise power. Noise, which is undesired audio that was not present at the transmitter's microphone, may come from a number of sources. These sources include the radio frequency energy in the path from the transmitter to the receiver, and also include noise from the electronics in the transmitter and the receiver. Figures of merit for SNR in body wires are given in the table below.

Rating	Signal to Noise (dB)
Poor	< 40
Moderate	45 to 65
Excellent	> 80

Table 6-5. Figure of Merit for Audio Signal to Noise Ratio

BIT ERROR RATE (BER) is another specification that affects audio quality. This specification applies to digital and digital spread spectrum systems, but not to narrowband FM systems. Bit error rate is the number of bits in the digital stream that have been received with the wrong value, compared to the total number of bits received.

Each bit in the digital (or digital spread spectrum) body wire received data stream has a value of 1 or 0. These bits taken together in preset groups (usually 8, 16 or 32 bits) form the 'words' which correspond to the digital representation of the audio waveform being transmitted. If one of these bits is somehow assigned the wrong value, the sound from the receiver will be distorted. The more bits that are assigned the wrong value, the worse the resulting audio.

Typically, bit error rate is expressed as the frequency of a single erroneous bit. For example, a bit error rate of 10^{-6} means that for every 1,000,000 bits sent, one of them will be received incorrectly, and the audio will be distorted for that instant. The table below shows figures of merit for bit error rates in body wire systems.

Rating	Bit Error Rate
Poor	10^{-4}
Good	10^{-5}
Excellent	10^{-6}
Excellent ++	10^{-7}
Outstanding	10^{-9}

Table 6-6. Figure of Merit for Bit Error Rate

Bit error rate has a relationship to receiver sensitivity. (Sensitivity is the weakest received signal power that can be successfully received.)   In general, receiver sensitivity is influenced by a change in bit error rate (and vice versa). A receiver with –100dBm sensitivity at a BER of 10^{-5}

could also have a sensitivity of –103 dBm at a BER of 10^{-4}. In the latter specification, the audio is worse, but the apparent range is better when compared to the former specification.

6.2.2 Transmission Range

The ability to receive the body wire signal at relatively long distances from the transmitter (agent) can be very useful in some law enforcement applications. High ranges allow the receiver to be located further from the agent, reducing the likelihood of physical discovery of the operation. In addition, for mobile applications, high ranges reduce the likelihood that an agent will move out of range of the receiver.

However, high ranges imply high transmit power. And high transmit power would reduce the electronic security of the system (increase the likelihood that wiretap detection equipment would see the signal coming from the transmitter). For this reason, the operation should use transmit power that is sufficient for the range of the operation, but not excessive.

Range evaluation is dependent on two manufacturer specifications: Transmitter (TX) power, and Receiver (RX) sensitivity. Path loss represents loss in signal power due to the transmission from body wore to receiver, and is an environmental factor which determines range for a given TX power and RX sensitivity. Path loss can not be specified by the manufacturer and needs to be accounted for by the user. There are many environmental factors that will increase path loss over a specific distance. Urban environments, with buildings and crowds of people may experience much greater path loss than in open terrain. From specifications of TX output power and RX sensitivity, the maximum path loss for received audio that can be accommodated by the system can be calculated.

In general, increasing transmitter output power will increase range for a particular terrain and RX sensitivity specification. The power should be expressed in mW or dBm (dBm = 10 x log base 10 of signal power in mW). There is no figure of merit for transmit output power since each operation will accommodate different equipment with different power ratings.

The table below presents some recommended transmit power values for various law enforcement applications.

Power Level	Remarks
< 20 mW	Use with caution – do trial run in the actual environment to be sure the equipment performs as required
20 mW to 100 mW	Short range applications but remain cautious in urban environment
100 mW to 200 mW	Good general purpose use
> 200 mW	Good, but size and battery requirements may be a problem

Table 6-7. Transmit Power Uses

The receiver sensitivity defines the lowest received power level of the transmitted signal that can be detected by the receiver at its antenna. A signal received at this level should provide audio output at the receiver. Receiver sensitivity should be quoted for a specific SNR. Sensitivity is usually given in dBm. Some radio frequency (FM) systems use a receiver sensitivity notation of microvolts (uV) for a specific SINAD (signal to noise plus distortion).

Typically specifications will be lower (better) for narrow bandwidth signals such as narrowband FM and higher for wider bandwidth signals such as digital spread spectrum. Note that sensitivity is stated with negative numbers since the power is less than 1 mW.

System Type	Good Receiver Sensitivity (dBm)
FM systems	-110 dBm or below -120 and below is very good
Digital systems	-90 to –110 dBm -103 and below is very good

Table 6-8. Receiver Sensitivity

In addition to transmit power and receiver sensitivity, path loss determines the range of the body wire system. Path loss is very dependent on physical conditions present in the locale of the transmitter and receiver and on the carrier frequency. Building structures, the number of people

between transmitter and receiver, interfering vehicles, metal wall studs, etc. (the local operating conditions) will server to attenuate the transmitted signal by varying amounts. It is not uncommon to see a requirement of a 8-fold increase in required power to double the range. Engineering studies have shown that in some cases, the attenuation at ground level is so great that output power must be increased 16 times in order to double the range. The expression often stated of 4 times the power to double the range is mainly applicable for line of sight conditions. Terrain is very important when looking at power outputs of different systems when trying to determine whether the equipment will meet range expectations.

A related concept to path loss is multipath. Multipath effects are due to portions of the signal arriving at the receiver at different times from the main signal, caused by reflections within the environment. These multiple signals arriving at the receiver may be highly disruptive to communications.

6.2.3 Battery Lifetime

Battery related specifications of body wires include maximum and minimum operating DC voltage and current drain. These specifications have a direct bearing on the type of battery most suitable for the equipment.

The current drain specification determines the amount of current required to run the equipment. The lower the current drain, the longer the equipment will run on a battery. Since many battery manufacturers list the battery capacity in mAh (milli ampere hours), it is quite easy to determine how long the equipment will run on a given battery. The current drain of the body wire equipment should be provided in the specifications.

The minimum operating voltage of a body wire is the minimum voltage that the battery must supply for the equipment to function properly. Generally, if the battery falls below this level, the equipment will cease operating. There may also be a maximum (not to exceed) voltage. Voltages beyond this figure will probably damage the equipment. The minimum operating voltage is often not given, but it is important in determining battery requirements.

In general, the less current consumed by the body wire, the longer the batteries will last. The lower the minimum operating voltage, the fewer batteries that are needed. The wider the operating voltage range (maximum voltage – minimum voltage), the longer the system will operate on a given battery pack.

NOTE: Always use new batteries. If the batteries have been taken out of their storage package, don't use them for field operation.

6.2.4 Physical Disguise

Two physical features are important for body wires: package size and antenna type. Dimensions should be given for length, width, and thickness. For body wire usage, the transmitter must be as thin as possible. It is also advantageous to remote the antenna from the transmitter. Being able to move the antenna away from the transmitter allows a greater choice of concealment options.

Rating	Thickness
Not good	> 0.5"
Adequate	0.375" to 0.5"
Good	0.25" to 0.375"
Excellent	0.125" to 0.25"
Superb	< 0.125"

Table 6-9. Figure of Merit for Size (Thickness)

6.2.5 Electronic Security

Narrowband scanners can easily detect Narrowband FM (NBFM) systems, since most detectors are of the narrowband sweep type. The fact that the signal is digitized is significant for electronic security, since it reduces the probability of interception. Digital spread spectrum systems are most secure.

Detection is defined as the ability of an outside person to discover the presence of the body wire signal. Detection can be accomplished with frequency counters, spectrum analyzers, or scanning receivers.

Interception is defined as the ability of an outside person to acquire the body wire signal and obtain understandable audio. A tunable receiver is necessary for this purpose. Spread spectrum systems have very good immunity to interception, since it is necessary for the outside person to

know the PN spreading sequence used in order to successfully receive the audio signal. If the PN sequence is kept confidential, randomly selected, and is long enough, it will be very difficult for an outside person to obtain understandable audio from the signal.

7. CURRENT AND PROJECTED STATE OF THE ART BODY WIRE TECHNOLOGY AREAS

7.1 Block Diagrams of Typical Body Wire Transmitters

This section will discuss the block diagrams of the digital, digital spread spectrum, and narrowband FM body wires. The block diagrams are intended to give the reader a general idea of the types of components used in body wires. Later sections will then briefly describe the state of the art for some of the key components used in body wires.

Figure 7-1 shows a simplified block diagram of a typical digital body wire transmitter. Starting at the top left of the figure, the audio signal is received by the microphone. Next, an amplifier/filter increases the voltage of the signal from the microphone to the correct level for the input to the analog to digital converter (ADC). Some filtering (removal) of unwanted signals may also occur in this block. The ADC converts the analog input signal to a digital word. The digital word output of the ADC is fed into a coding block, which adds bits to the ADC words that will serve to detect and correct errors at the receiving end of the body wire link. After these error detection and correction bits are added, the resulting bit stream is differentially encoded for differential phase shift key (DPSK) modulation. The resulting bit stream is fed to a binary phase shift keyed (BPSK) digital modulator. (Other digital modulation methods could also be used, but this particular block diagram uses BPSK). The BPSK digital modulator changes the phase of the radio frequency (RF) carrier (from the RF synthesizer), according to whether a 0 or 1 bit is input. The resulting phase modulated carrier then goes to the power amplifier block. The power amplifier block increases the power of the modulated RF carrier to a level that is suitable for transmission. The power amplifier output goes to an antenna matching network, which assures that the power of the amplified phase modulated RF signal from the power amplifier is efficiently transferred to the antenna. The matching network feeds the antenna, which sends the signal through the air to the receiver.

Batteries and voltage regulators provide power for the body wire. The battery voltage is applied to voltage regulators, which provide the voltages needed by various components in the body wire.
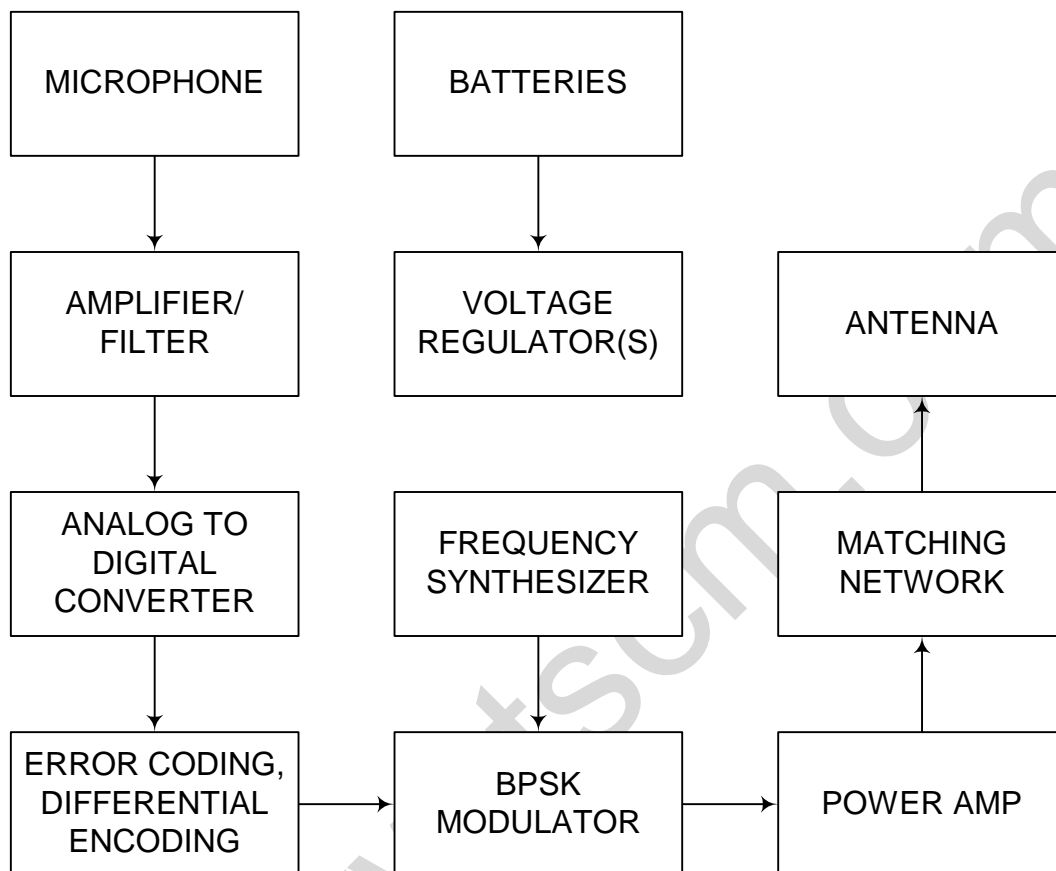

Figure 7-1. Digital body wire block diagram.

Figure 7-2 shows a block diagram of a digital spread spectrum body wire. The diagram is very similar to the diagram for the digital body wire, except for the addition of a PN sequence generator and an exclusive or (XOR) block. The PN sequence generator generates a random sequence of bits (chips) that is fed to the XOR block. The XOR block combines the PN sequence with the data bits from the differential encoding block. The resulting bit stream is fed to the digital modulator (a BPSK modulator is shown).

Adding the PN bit sequence increases the bit rate going into the BPSK modulator, and thereby increases the bandwidth of the modulated signal around the RF carrier (the bandwidth of a phase

shift keyed signal is approximately twice the bit rate). This increased bandwidth can make a spread spectrum signal more difficult to detect, since the energy of the signal is spread out over a wider band of frequencies.
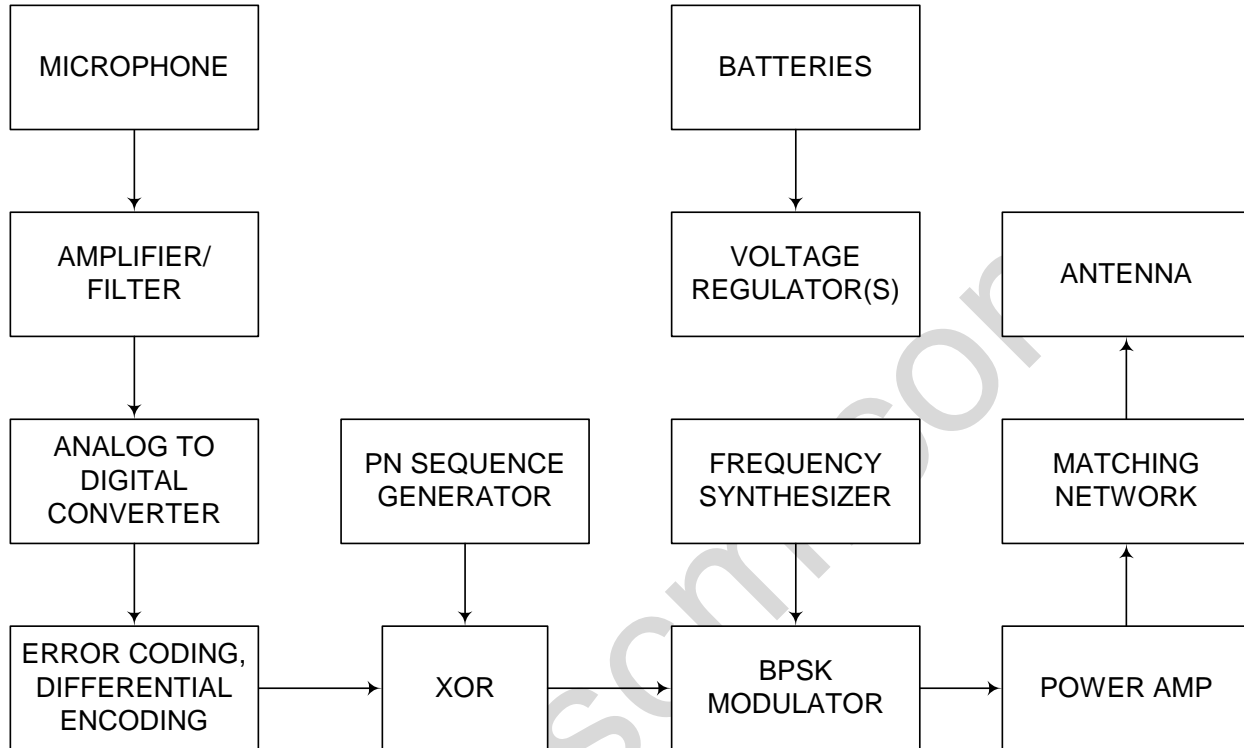

Figure 7-2. Direct Sequence Spread Spectrum body wire block diagram.

Figure 7-3 shows a block diagram of a typical narrowband FM body wire transmitter. The main difference in this system and the digital body wire is that analog modulation is used instead of digital modulation. The analog signals from the microphone's amplifier/filter are fed to the FM input on the frequency synthesizer, which frequency modulates the carrier. The output of the frequency synthesizer goes to a power amp. The power amplifier output goes to a matching network, and the matching network feeds the antenna.

The frequency synthesizer consists of several components: a voltage controlled oscillator (VCO), a divide by N counter, a phase/frequency detector, and a loop filter. A temperature compensated crystal oscillator (TCXO) serves as a frequency reference for the frequency synthesizer. The frequency synthesizer is used in the narrowband FM, the digital, and the digital spread spectrum body wires.
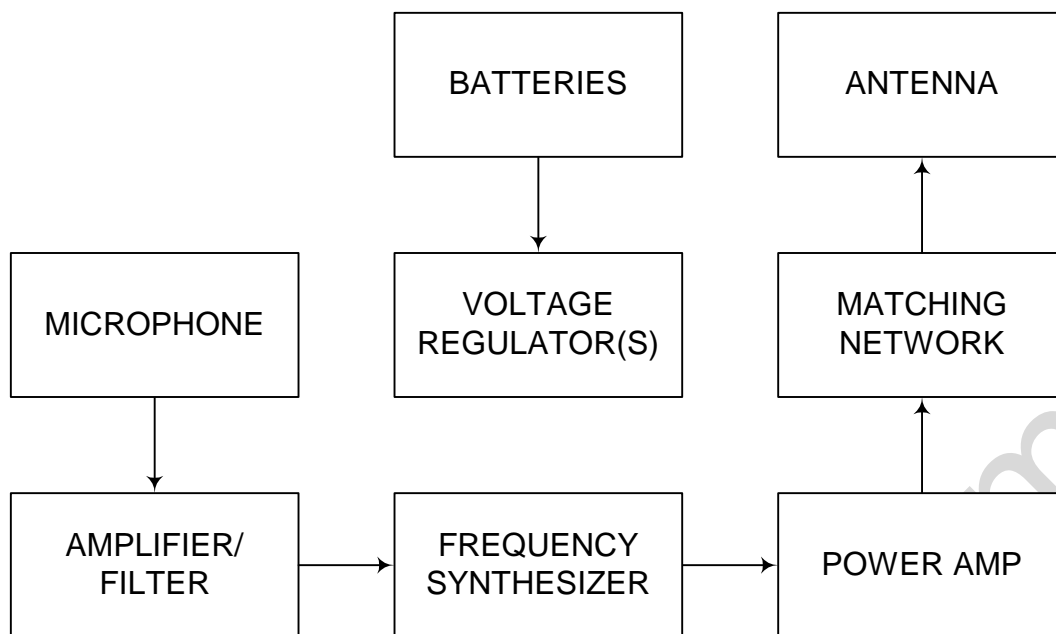
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┌─────────────┐      ┌─────────────┐
│  BATTERIES  │      │   ANTENNA   │
└──────┬──────┘      └──────▲──────┘
       │                    │
┌────────────┐ ┌─────────────┐ ┌─────────────┐
│ MICROPHONE │ │   VOLTAGE   │ │  MATCHING   │
│            │ │ REGULATOR(S)│ │   NETWORK   │
└─────┬──────┘ └─────────────┘ └──────▲──────┘
      │                               │
┌────────────┐ ┌─────────────┐ ┌─────────────┐
│ AMPLIFIER/ │→│  FREQUENCY  │→│  POWER AMP  │
│   FILTER   │ │ SYNTHESIZER │ │             │
└────────────┘ └─────────────┘ └─────────────┘
```

Figure 7-3. Narrowband FM body wire block diagram.

Please note that many variations on all three of the above block diagrams are possible. The intent is to give typical block diagrams, and to give the reader a general idea of the types of components used in body wires.

7.2 Microphones

(See the discussion on microphones in the solid state audio recorder section)

7.3 Analog to Digital Converters

(See the discussion on delta sigma analog to digital converters in the solid state audio recorder section)

7.4 Frequency Synthesizer

The frequency synthesizer provides the RF carrier used by the transmitter. A typical frequency synthesizer consists of several components: a temperature compensated crystal oscillator (TCXO), a phase-frequency detector, a loop filter, a voltage controlled oscillator (VCO), and a divide by N circuit (prescaler). The phase-frequency detector compares the phase of the divided

VCO with the phase of the TCXO. The loop filter filters the output of the phase frequency detector, and the output of the loop filter is applied to the voltage control input of the VCO. If the phase of the divided VCO is different than the phase of the TCXO, the voltage applied to the VCO will change the VCO frequency until the phase of the TCXO is aligned with the phase of the divided VCO. In this manner, the frequency of the VCO is controlled so that it is N times the frequency of the TCXO. By adjusting the value of N, it is possible to generate different frequencies.

Low cost, low power integrated circuits are available to perform one or more of the functions needed by the frequency synthesizer. For example, the National Semiconductor LMX2346 provides the phase-frequency detector and divide by N functions. It consumes 6mA of current and costs $2.05 in quantities of 1000. It is available in small surface mount packages including a 0.25" x 0.2" package and an even smaller chip scale package. A very good TCXO part is the ECS 39SM series made by ECS, Inc. This part consumes 1.5mA at 3.3V and has a very good frequency accuracy of 1.5 ppm. It is available in a surface mount package that is 0.45" x 0.38", and costs $7.70 in quantities of 1000. An example of a VCO that will cover the the 915MHz ISM band (for a direct conversion transmitter) is the Maxim 2623. This part consumes 9mA at 3.3V, is available in a 3.0mm x 4.9mm (uMax) package, and sells for $1.80 in quantities of 1000. The loop filter may be constructed from passive components (resistors and capacitors) for only a few cents in cost and with very small packages.

Future frequency synthesizer components should benefit from the overall trend in electronics toward smaller die geometries. Smaller geometries may be operated with lower supply voltages, resulting in lower power consumption. Smaller geometries can also lead to smaller IC sizes or greater part densities. The use of synthesizer components in high volume cell phone and cordless phone markets should ensure the continued development and availability of low cost, power efficient, small size frequency synthesizer components.

7.5 Power Amplifiers

In most body wire designs, the power amplifier consumes more power than any other single element. For that reason, operating times for the body wire are dictated largely by the power needed by the power amplifier.

One of the biggest decisions in selection of a power amplifier is dictated by whether or not a constant envelope waveform type of modulation is used. If a constant envelope modulation is used, then one of the more power efficient amplifier classes may be used (Class B, AB, or even C). In contrast, if a modulation technique is selected that is not constant envelope, then a less power efficient amplifier class (Class A) must be used.

One problem with using the more power efficient amplifiers is they do not operate in the linear region, and are subject to spectral regrowth. A current area of research in power amplifiers for wireless applications is how to improve the spectral regrowth problems in power efficient amplifiers. Several techniques to prevent spectral regrowth and preserve efficiency are being investigated. One such technique is to adaptively bias the power amplifier so it operates in the most efficient region of class A operation all the time. Another technique is to predistort the waveform, so that it is relatively undistorted after it is amplified by a Class C amplifier.

An example of a state of the art, low cost amplifier for constant envelope waveforms in the 900MHz ISM band is the Maxim MAX2235. It features a +30dBm (1W) power output, 47 percent efficiency, has a footprint of 6.4 x 6.5mm, and sells for $2.07 in quantities of 1000.

The continued growth in wireless commercial applications (such as cell phones, wireless phones, PCS, Bluetooth, HomeRF, and wireless LANs) is expected to spur future development of more efficient power amplifiers.

8. PROJECTED COMMERCIAL BODY WIRE PRODUCTS (IN TWO YEARS)

It can be anticipated that body wire equipment capabilities will undergo a steady change in the next two years. The forecast is that digital technology will be assume as more prominent role in wireless operations. The benefits of security and audio quality will become more in demand. The challenge to the designers and manufacturers is to bring digital equipment into the same range performance standard as analog and still keep costs down. Digital, because of its additional complexity, is inherently more expensive than analog. Unfortunately, digital operation will be faced with a range penalty and the way to increase range is to engineer more efficiency and range enhancements into the digital equipment. This extra engineering comes with an added cost burden. Operational requirements demand the best quality audio for evidentiary and investigative purposes, which is of course directly in the province of digital technology. Better education and training is the way around the seemingly contradictory desires of performance and cost. Properly trained personnel will understand the benefits and drawbacks of digital equipment

and will be able to get the results needed in the difficult investigations involving foreign translations and poor audio environments. Well trained technicians will be able to get good audio at the ranges required, making the change-over from analog to digital much less painful.

9. BODY WIRE CONCLUSIONS

Body wire equipment is currently available in a wide variety of size, technology and operating lifetime. The old adage "You get what you pay for" is ever applicable. Good analog equipment is not cheap, neither are good digital transmitters and receivers. Cheap equipment manifests itself in shoddy performance and poor reliability, in spite of claims of high quality . Written specifications can give a distorted picture to the unknowing. The best advice one can get is to become knowledgeable about the meaning of equipment specifications and their operational impact. One must evaluate equipment prospects as to performance and operational tradeoffs – then consider cost. It has been the case that a law enforcement user has said that a certain piece of equipment is the only thing that can be afforded, only to discover that the product is quite useless. The small savings in equipment cost can cause a much larger loss of funds when the entire case is destroyed because the jury could not understand the spoken word or the translator could not properly comprehend the idiomatic speech.

APPENDIX A

SOLID STATE RECORDER PRODUCT MATRIX

The following spreadsheet contains a complete listing of the data collected on the various types of recorders investigated. Many of the desired specifications were not available or were considered too proprietary to release, particularly related to details regarding the type of encoding used for the voice recording.

Table A-1. Commercial Off-The-Shelf (COTS) Audio Recorder Products.

Maker	Model	Size	Wt	Record Time	Power Needs	Nom. SNR (dB)	Bandwidth	Dynamic Range	Cost	PC Interface	Stereo/ Mono	Voice Encoding	Sample Freq / Bit Rate
Memorex	MB002	2.17" x 3.58" x 0.59"	3.8 oz	16 min	2 AAA, 5 hr record				39.99	No	Mono		
Memorex	MB005	2.38" x 4.25" x 0.85"	4 oz	32 min	2 AAA, 5 hr record				49.99	No	Mono		
Netvox	V901	85mm x 60mm x 52mm	70 g w/ batt	15 min	2 AAA (3V), 75 mA record					No	Mono		4.8kbps compress
Netvox	V901P	85mm x 60mm x 52mm	70 g w/ batt	60 min	2 AAA (3V), 75 mA record					No	Mono		4.8kbps compress
Olympus	DS150	4.6" x 1.6" x 0.6"	2.9 oz w/o batt	LP:160 min SP:75 min (8MB Int)	2 AAA, 10 hr record	Line-in:44 Built-in Mic: 38	LP:300Hz-3kHz SP:300Hz-5kHz	60	179.00	Serial/ USB	Mono	DSS (Digital Speech Standard)	SP:12kHz, 13.7kbps LP:8kHz, 6.3kbps
Olympus	D1000	4.7" x 1.81" x 0.91"	5.5 oz w/o batt	LP:34 min SP:16 min w/ 2MB card; LP:72 min SP:33 min w/ 4MB card	2 AA, 8 hr record + CR1220 Li button	Line-in:44 Built-in Mic: 38	LP:200Hz-2kHz SP:200Hz-5kHz	55	214.00	Laptop/ PC Adapter Card (PCMCIA)	Mono	SCVA (Silent Compress Voice Activ)	SP:12kHz LP:8kHz
Olympus	V90	4.5" x 1.5" x 0.5"	1.6 oz w/o batt	LP:90 min SP:33 min	1 AAA, 10 hr record	Built-in mic: 41	LP:300Hz-1.7kHz SP:300Hz-3.5kHz	48	108.00	No, Headphone Jack Only	Mono		
Olympus	VN90	4.6" x 1.6" x 0.6"	2.3 oz	LP:90 min SP:33 min	2 AAA, 17 hr record	Built-in mic: 41	LP:300-1.7kHz SP:300-3.5kHz	48	93.00	No, Headphone Jack Only	Mono		
Olympus	VN180	4.6" x 1.6" x 0.6"	2.3 oz	LP:180 min SP:66 min	2 AAA, 17 hr record	Built-in mic: 41	LP:300Hz-1.7kHz SP:300Hz-3.5kHz	48	119.00	No, Headphone Jack Only	Mono		
Panasonic	RR-QR240	2.2" x 3.5" x 0.5"	2 oz	LP:240min SP:120 min HQ:60 min	2 AAA (3V), 30 hr record	37 (Built-in Mic, HQ mode)	HQ:450Hz-5.0kHz		146.00	No, Earphone Out Only	Mono		
Panasonic	RR-QR80	2.2" x 3.5" x 0.5"	2 oz	LP:60min SP:30 min HQ:15 min	2 AAA (3V), 30 hr record	37 (Built-in Mic, HQ mode)	HQ:450Hz-5.0kHz		92.00	No, Headphone Jack Only	Mono		

Table A-1. Commercial Off-The-Shelf (COTS) Audio Recorder Products (rightmost columns).

Maker	Model	Time/ Date Stamp	Mic Ext/Int	Removable Memory?	Memory Size (MB)	Notes	URL
Memorex	MB002	No	Int	Built in Flash		VOR capable	http://store.yahoo.com/igadget/digvoicrec1.html
Memorex	MB005	No	Int	Built in Flash			http://store.yahoo.com/igadget/digvoicrec1.html
Netvox	V901	No	Int	Built in Flash	4		http://www.netvox.com.tw/english/vrecorder.htm
Netvox	V901P	No	Int	Built in Flash	16		http://www.netvox.com.tw/english/vrecorder.htm
Olympus	DS150	Yes	Both	Built in Flash	8	VOR capable. Hi/Lo Mic. Pkg w/ ViaVoice software for $220.	http://www.zap1.com/comparisons.html
Olympus	D1000			Intel Removable Flash Memory Cards: 2, 4, 8MB available	8	8MB cards available (SP:72 min LP:148min). VOR Capable. Pkg w/ ViaVoice software for $289.99. Opt Flash Card Reader/ Writer for PC.	http://www.zap1.com/comparisons.html
Olympus	V90	No	Int	Built in IC		VOR Capable. Hi/Lo Mic	http://www.zap1.com/comparisons.html
Olympus	VN90	No	Both	Built in IC		VOR Capable. Hi/Lo Mic	http://www.zap1.com/comparisons.html
Olympus	VN180	No	Both	Built in IC		VOR Capable. Hi/Lo Mic	http://www.zap1.com/comparisons.html
Panasonic	RR-QR240	Yes	Both	Built in Flash	32	VOR Capable. Hi/Lo Mic	http://www.prodcat.panasonic.com/shop/product.asp?sku=RR-QR240&CategoryID=225
Panasonic	RR-QR80	Yes	Both	Built in Flash	8	Same as RR-QR240 but less memory	http://www.prodcat.panasonic.com/shop/product.asp?sku=RR-QR80&CategoryID=225

Table A-1. Commercial Off-The-Shelf (COTS) Products (continued).

Maker	Model	Size	Wt	Record Time	Power Needs	Nom. SNR (dB)	Bandwidth	Dynamic Range	Cost	PC Interface	Stereo/ Mono	Voice Encoding	Sample Freq / Bit Rate
Samsung	Voice Pen SVR-P220	6" x 0.65" diam	2 oz	LP:138min SP:70min	1 AAA, 8 hr record	Built-in mic: 40	500Hz-3.5kHz		229.00	Line Out Jack	Mono	ADPCM	
Samsung	Voice Pen SVR-P700	5.8" x 0.7" diam	2 oz	70 min	1 AAA, 4 hr record	Built-in mic: 40	100Hz-4kHz		185.00	Line Out Jack	Mono	ADPCM	
Samsung	Voice Stick SVR-S820	102mm x 36mm x 17mm	64 g w/ batt	LP:502min SP:233min	2 AAA, 10 hr record		500Hz-3.5kHz		225.00	Line Out Jack	Mono		SP:9.5kbps LP:4.7kbps
Samsung	Voice Stick SVR-B410	4.75" x 1" x 0.5"	1.5 oz	LP:250min SP:115min	2 AAA, 8 hr record		500Hz-3.5kHz		160.00	Line Out Jack	Mono		
Samsung	Digital Recorder SVR-N200	3.5" x 2.1" x 0.9"	2 oz	LP:119min SP:59min	2 AAA, 10 hr record		500Hz-3.5kHz		99.00	Line Out Jack	Mono		
Sony	ICD-R100	0.5" x 4" x 1.75"	68g w/ batt	LP:150min SP:64min	2 AAA (3V), 19 hr record		SP:280Hz-4.8kHz LP:240Hz-3.2kHz		169.95	Parallel	Mono	ICS (Sony ADPCM)	SP:11kHz LP:7kHz
Sony	ICD-R100PC	0.5" x 4" x 1.75"	68g w/ batt	LP:150min SP:64min	2 AAA (3V):19 hr record		SP:280Hz-4.8kHz LP:240Hz-3.2kHz		199.95	Parallel	Mono	ICS (Sony ADPCM)	SP:11kHz LP:7kHz
Sony	ICD-70PC	0.938" x 3.375" x 2.375"	1.8 oz w/o batt	LP:24min SP:16min	2 AAA (3V)				179.95	Parallel	Mono	ICS (Sony ADPCM)	
Sony	ICD-35	0.875" x 3.375" x 2.125"	2 oz w/o batt	LP:32min SP:16min	1 AAA (1.5V), 6 hr record				79.99	No	Mono	ICS (Sony ADPCM)	SP:8kHz
Sony	ICD-37	0.875" x 3.375" x 2.125	2.75 oz w/o batt	45min	1 AAA (1.5V), 5 hr record		280Hz-2.8kHz		99.95	No	Mono	MSV or ICS (Sony ADPCM)	6.5kHz
Sony	ICD-55	2.125" x 3.375" x 0.875"	2 oz w/o batt	LP:64 min SP:32 min	1 AAA (1.5V), 6 hr record				99.99	No	Mono	ICS (Sony ADPCM)	SP:8kHz

Table A-1. Commercial Off-The-Shelf (COTS) Audio Recorder Products (rightmost columns) (continued).

Maker	Model	Time/ Date Stamp	Mic Ext/Int	Removable Memory?	Memory Size (MB)	Notes	URL
Samsung	Voice Pen SVR-P220	No	Int	Built in Flash	16	10 levels of volume control (digital). Output to PC not usable for speech-to-text programs.	http://www.zap1.com/comparisons.html
Samsung	Voice Pen SVR-P700	No	Int	Built in Flash	8	10 levels of volume control (digital). Output to PC not usable for speech-to-text programs.	http://www.zap1.com/comparisons.html
Samsung	Voice Stick SVR-S820	No	Both	Built in Flash	16	10 levels of volume control (digital). VOR Capable	http://www.zap1.com/comparisons.html
Samsung	Voice Stick SVR-B410	No	Both	Built in Flash	18	10 levels of volume control (digital). VOR Capable	http://www.zap1.com/comparisons.html
Samsung	Digital Recorder SVR-N200	No	Both	Built in Flash	18		http://www.zap1.com/comparisons.html
Sony	ICD-R100	Yes	Both	Built in IC Flash	16	VOR capable, Hi/Lo Mic, same as ICD-R100 PC but w/o PC Interface pkg	http://www.sel.sony.com/SEL/consumer/icrecorder/features_comparison.html
Sony	ICD-R100PC	Yes	Both	Built in IC Flash	16	VOR Capable, Hi/Lo Mic, Hold Switch	http://www.sel.sony.com/SEL/consumer/icrecorder/features_comparison.html
Sony	ICD-70PC	Yes	Both	Built in IC Flash	4	VOR Capable, Hi/Lo Mic, Min Record Segment 4 sec, Hold Switch	http://www.sel.sony.com/SEL/consumer/icrecorder/features_comparison.html
Sony	ICD-35	No		Built in IC Flash	4		http://www.sel.sony.com/SEL/consumer/icrecorder/features_comparison.html
Sony	ICD-37	Yes	Int	Built in IC Flash		Hi/Lo Mic, Hold Switch	http://www.sel.sony.com/SEL/consumer/icrecorder/features_comparison.html
Sony	ICD-55	No		Built in IC Flash	8		http://www.sel.sony.com/SEL/consumer/icrecorder/features_comparison.html

47

Table A-1. Commercial Off-The-Shelf (COTS) Products (continued).

Maker	Model	Size	Wt	Record Time	Power Needs	Nom. SNR (dB)	Bandwidth	Dynamic Range	Cost	PC Interface	Stereo/ Mono	Voice Encoding	Sample Freq / Bit Rate
Sony	ICD-67	2.125" x 3.375" x 0.875"	2.75 oz w/o batt	180 min	1 AAA, 5 hr record		280Hz-2.8kHz		129.95	No	Mono	ICS (Sony ADPCM)	6.5kHz
Sony	ICD-V21	2.125" x 3.375" x 0.875"	2.75oz	10 min Max	1 AAA, 6 hr record				89.95	No	Mono	ICS (Sony ADPCM)	
Sony	ICD-MS1	1.75" x 4.25" x 0.667"	3.1 oz (w/ batt)	LP:131 min (8kHz samp) SP:63 min (11kHz samp) w/ 16MB Stick	2 AAA (3V), 5 hr record		SP:240Hz-4.8kHz LP:240Hz-3.2kHz		299.95	Line Out Only, Parallel port PC-card reader or PCMCIA card adapter available for Stick Media	Mono	MSV (Sony ADPCM)	SP:11kHz LP:7kHz
Sillacom	Clue 240	5.1" x 1.2" x .65"	2 oz	LP:233 min SP:116 min	2 AAA				129.00	Line Out Jack	Mono		
Sillacom	Clue 480	5.1" x 1.2" x .65"	2 oz	LP:506 min SP:231 min	2 AAA				150.00	Line Out Jack	Mono		
Sillacom	Clue 560	5.1" x 1.2" x .65"	2 oz	LP:556 min SP:255 min	2 AAA				165.00	Line Out Jack	Mono		
Voice-It	VT-90	3.5" x 2.25" x 0.33"	2 oz	1.5 min	4 CR2025 Lithium Cells				39.00	No	Mono		
Voice-It	VT-300	3.5" x 2.25" x 0.5"	2 oz	5 min	1 AAA				55.00	No	Mono		
Voice-It	VT-700	3.5" x 2.25" x 0.5"	2 oz	LP:22 min SP:16 min HQ:12 min	1 AAA					No	Mono		
Voice-It	VR-1000	4.75" x 2.25" x 1"	3.5 oz	50 min w/ built-in memory, extra 50 min w/ memory card	2 AAA				118.00	Serial or USB	Mono		

Table A-1. Commercial Off-The-Shelf (COTS) Audio Recorder Products (rightmost columns) (continued).

Maker	Model	Time/ Date Stamp	Mic Ext/Int	Removable Memory?	Memory Size (MB)	Notes	URL
Sony	ICD-67	Yes	Int	Built in IC Flash		Hi/Lo Mic, Hold Switch	http://www.sel.sony.com/SEL/consumer/icrecorder/features_comparison.html
Sony	ICD-V21	No		Built in IC Flash			http://www.sony.com/
Sony	ICD-MS1	Yes	Both	Yes, Memory Stick media	8MB to 64MB Memory Stick Media (256MB under develop-ment)	Voice files converted to 16-bit WAV files in PC, VOR capable, Hi/Lo Mic, Write Protect Switch on Back, approx. 1hr voice record for every 16 MB, rated "Best Performance" by Dragon Speech Recognition Software evaluation	http://www.sony.com/
Sillacom	Clue 240			Built in IC			http://www.zap1.com/comparisons.html
Sillacom	Clue 480			Built in IC			http://www.zap1.com/comparisons.html
Sillacom	Clue 560			Built in IC			http://www.zap1.com/comparisons.html
Voice-It	VT-90			Built in IC			http://www.zap1.com/comparisons.html
Voice-It	VT-300			Built in Flash			http://www.zap1.com/comparisons.html
Voice-It	VT-700			Built in Flash			http://www.smoltz.com/
Voice-It	VR-1000			Both, Built in Flash plus memory card slot		Has slot for additional SSFDC memory card	http://www.smoltz.com/

Table A-1. Commercial Off-The-Shelf (COTS) Products (continued).

Maker	Model	Size	Wt	Record Time	Power Needs	Nom. SNR (dB)	Bandwidth	Dynamic Range	Cost	PC Interface	Stereo/ Mono	Voice Encoding	Sample Freq / Bit Rate
Voice-It	VX-1200	3.5" x 2.5" x 0.75"	2 oz	12 min	1 AAA				71.00	No	Mono		
Voice-It	VX-3400	3.5" x 2.5" x 0.75"	2 oz	LP:34 min SP:23 min HQ:17 min	1 AAA				79.00	No	Mono		
Voice-It	VTR-3200	4.75" x 2.25" x 1.0"	3.5 oz	LP:74 min SP:55 min HQ:40 min	2 AAA, 10 hr record				200.00	Serial, 16.7-33.3 kbps	Mono		LP:6kHz SP:8kHz HQ:11kHz
Voice-It	VM-15	4.24" x 2.25" x 0.75"	3.8 oz	22 min	AAA				88.00	No			
Voice-It	VM-30	4.24" x 2.25" x 0.75"	3.8 oz	45 min	AAA				98.00	No			
Univex	SPD25U/ 100U Voica digital recorder	113mm x 55mm x 14mm	58g	25-100 min (2 to 8 MB)	2 AAAA				289.00	Yes			
	8-hour Voice Recorder	4" x 1.375"	502 min	2 AAA, 10 hr record				199.95	Yes				
MP3													
Creative Labs	NOMAD 64	85mm x 58mm x 17mm	64 g w/o batt	120min record time	2 AAA (5 hrs play time)	>90 dB	20Hz - 20kHz MP3		202.95	Parallel			

50

Table A-1. Commercial Off-The-Shelf (COTS) Audio Recorder Products (rightmost columns) (continued).

Maker	Model	Time/ Date Stamp	Mic Ext/Int	Removable Memory?	Memory Size (MB)	Notes	URL
Voice-It	VX-1200			Built in Flash	?		http://www.zap1.com/comparisons.html
Voice-It	VX-3400			Built in Flash	?		http://www.zap1.com/comparisons.html
Voice-It	VTR-3200	Yes	Both	Both, 4MB Int Flash, expandable w/ 2/4/8MB Cards	4 Int Flash, 2/4/8 Cards	HQ mode recommended for voice-to-text apps. Slot for additional SSFDC 2/4/8MB 3.3V SmartMedia memory card. Voice stored on built-in and card memory w/ approx. 20 min for every 2MB in HQ mode. This model used by Dragon Naturally Speaking voice-to-text software package. SDK kit available. No insert message capability.	http://www.zap1.com/comparisons.html
Voice-It	VM-15			Built in	?	Automatic phone dialing	http://www.zap1.com/VM-30homepage.html
Voice-It	VM-30			Built in	?	Automatic phone dialing	http://www.zap1.com/VM-30homepage.html
Univex	SPD25U/ 100U Voica digital recorder			Built in?	2 to 8	Memory size from 2MB to 8MB	http://www.scandy.com/univex/
	8-hour Voice Recorder			Built in Flash	16	Voice activated? Has 16MB flash memory	http://www.lifestylefascination.com/
MP3							
Creative Labs	NOMAD 64			Both, Built in Flash plus Smartmedia Flash slot	32 Int, 32 Smartmedia Cards	MP3 Player/Voice Recorder. 1 memory card slot. 32MB built in with 32MB (max) removable SmartMedia Flash card.	http://www.egghead.com/category/inv/00057584/02289391.htm

51

Table A-1. Commercial Off-The-Shelf (COTS) Products (continued).

Maker	Model	Size	Wt	Record Time	Power Needs	Nom. SNR (dB)	Bandwidth	Dynamic Range	Cost	PC Interface	Stereo/Mono	Voice Encoding	Sample Freq / Bit Rate
Creative Labs	NOMAD II	65mm x 93mm x 21mm	88 g w/o batt	Up to 240min record time on 64MB SmartMedia	1 AA, 1.5V (10 hrs play time)	>90 dB	20Hz - 20kHz MP3		399.95	USB or opt. Docking station		Proprietary G.721 4-bit ADPCM @ 32kbps	8kHz, 16-bit record prior to ADPCM encoding
Creative Labs	NOMAD II MG	58mm x 90mm x 18mm	77.1 g w/o batt	Up to 240min record time on 64MB built-in memory	2 AAA (10 hrs play time)	>90 dB	20Hz - 20kHz MP3		799.99	USB via Docking station		Proprietary G.721 4-bit ADPCM @ 32kbps	8kHz, 16-bit record prior to ADPCM encoding
eGO	i2GO	2.75" x 1.25" x 4.5"	7 oz	64MB (240min), 96MB, 170MB, 340MB	2 AA	90dB	20 - 15kHz		219 - 399	USB			
Varo Vision	VaroMan			130min Voice	1 AA, 1.5V (12 hrs play time)	90dB				Parallel		ADPCM Voice	
Varo Vision	VaroMan II			130min Voice	2 AAA	90dB				USB		ADPCM Voice	

Table A-1. Commercial Off-The-Shelf (COTS) Audio Recorder Products (rightmost columns) (continued).

Maker	Model	Time/ Date Stamp	Mic Ext/Int	Removable Memory?	Memory Size (MB)	Notes	URL
Creative Labs	NOMAD II			Removable SmartMedia only	64 Max	"SDMI compliant". Uses removable flash memory cards (64 MB max). Has FM Tuner. Plays MP3, WMA format music.	http://www.layer3.org/devices/portables.html
Creative Labs	NOMAD II MG			Both, Built in Flash plus Smartmedia Flash slot	64 Int, 16/32/64 Smartmedia Cards	"SDMI compliant". 64MB built-in int. memory plus removable SmarMedia Card slot (64 MB max). Has FM Tuner. Plays MP3, WMA format music.	http://www.layer3.org/devices/portables.html
eGO	i2GO			Both, Built in Flash plus Flash card slot plus ext hard drive capability	64, 96, 170(HD), 340(HD)	MP3 Player with several memory options in the form of compact flash cards. Approximately 1MB for 4 minutes of recording	http://www.layer3.org/devices/portables.html
Varo Vision	VaroMan		Int	Both, Built in Flash plus Smartmedia Flash slot	32 Int, 16/32 Smartmedia Cards	MP3 Player & Voice Recorder. 32MB = 130min voice recording time. Built-in mic. Built-in 32MB, expandable by 16/32MB SmartMedia Card.	http://www.varovision.com/sub1/vman.html
Varo Vision	VaroMan II		Int	Both, Built in Flash plus Smartmedia Flash slot	32/64 Int, 16/32 Smartmedia Cards	MP3, MS Audio (WMA) Player & Voice Recorder. 32MB = 130min voice recording time. Built-in mic. Built-in 32/64MB, expandable by 16/32MB SmartMedia Card.	http://www.varovision.com/sub1/vman.html

Table A-1. Commercial Off-The-Shelf (COTS) Products (continued).

Maker	Model	Size	Wt	Record Time	Power Needs	Nom. SNR (dB)	Bandwidth	Dynamic Range	Cost	PC Interface	Stereo/ Mono	Voice Encoding	Sample Freq / Bit Rate
Varo Vision	VaroMan Plus			170min Voice on 40MB *Clik!* disk	LiIon Recharge (12 hr play time)	90dB				Parallel, USB optional		ADPCM Voice	
Varo Vision	VaroMan Super												
Sensory Science	raveMP 2000	2.67" x 3.7" x .67"	70g, w/o batt	120min Voice on 32MB built-in memory only	1 AA, 1.5V (10 hrs play time)	70dB	20Hz - 20kHz		50.00	Parallel (up to 150kbps R/W)	Mono Voice Record	ADPCM Voice, MP3 Music	Voice: LP:33kbps/ 8kHz SP:66kbps / 16kHz HQ:132kbps/ 32kHz
Sensory Science	raveMP 2100	2.67" x 3.7" x .67"	70g, w/o batt	240min Voice on 64MB built-in memory only	1 AA, 1.5V (10 hrs play time)	70dB	20Hz - 20kHz		189.99	Parallel (up to 150kbps R/W)	Mono Voice Record	ADPCM Voice, MP3 Music	Voice: LP:33kbps/ 8kHz SP:66kbps / 16kHz HQ:132kbps/ 32kHz
Sensory Science	raveMP 2200	2.26" x 3.29" x .68"	74g, w/o batt	240min Voice on 64MB built-in memory only	1 AA, 1.5V (10 hrs play time)	90dB	20Hz - 20kHz		264.94	USB (up to 350kbps R/W)	Mono Voice Record	ADPCM Voice, MP3 Music	Voice: 32kbps/ 8kHz
Sensory Science	raveMP 2300	2.8" x 4.8" x .8"	7.4 oz	150min mono Voice, 75min stereo Music on 40MB Clik! disk	LiIon Recharge (12 hr play time)	90dB	20Hz - 20kHz		299.00	USB (up to 350kbps R/W), Clik! Disc (up to 1Mbps)	Mono Voice Record	ADPCM Voice, MP3, Microsoft WMA4, AAC Music	Voice: LP:33kbps/ 8kHz SP:66kbps / 16kHz HQ:132kbps/ 32kHz
Audio Request	Ondigo	66mm x 90mm x 18mm		4 hrs Max	2 AAA (10 hrs play time)	90dB			249.95	Parallel (2Mbps max)		ADPCM	

Table A-1. Commercial Off-The-Shelf (COTS) Audio Recorder Products (rightmost columns) (continued).

Maker	Model	Time/ Date Stamp	Mic Ext/Int	Removable Memory?	Memory Size (MB)	Notes	URL
Varo Vision	VaroMan Plus		Int	Removable 40 MB Clik Discs Only	40	MP3, MS Audio (WMA) Player & Voice Recorder. Clik! Disc only, no internal memory. All Clik! disc drives reportedly produce an audible hum when operating (MP3.com review).	http://www.varovision.com/sub1/vman.html
Varo Vision	VaroMan Super					Not yet available.	http://www.varovision.com/sub1/vman.html
Sensory Science	raveMP 2000	Yes	Int, Line In	Both, Built in Flash plus Flash slot	32 Int, 16/32 Flash Cards	MP3 Player with 32MB built in memory (expandable to 64MB w/ 32MB Flash Memory Card) and built in mic	http://www.layer3.org/devices/portables.html
Sensory Science	raveMP 2100	Yes	Int, Line In	Both, Built in Flash plus Flash slot	64 Int, 16/32 Flash Cards	MP3 Player with 64MB built in memory (expandable to 96MB w/ 32MB Flash Memory Card) and built in mic	http://www.layer3.org/devices/portables.html
Sensory Science	raveMP 2200	No	Int	Both, Built in Flash plus Flash slot	64 Int, 16/32/64 Flash Cards	MP3 Player with 64MB built in memory (expandable to 126MB w/ 64MB SmartMedia Card) and built in mic	http://www.layer3.org/devices/portables.html
Sensory Science	raveMP 2300		Int	40 MB Clik Discs	40	MP3/WMA Player with 0MB built in memory and built in mic; ZDNet review claims "muted & fuzzy" voice record	http://www.layer3.org/devices/portables.html
Audio Request	Ondigo			Both, Built in Flash plus Smartmedia Flash slot	64 Int, SmartMedia Slot	MP3 player, FM tuner, 250 number phone directory, SmartMedia expansion slot.	http://www.layer3.org/devices/portables.html

55

Table A-1. Commercial Off-The-Shelf (COTS) Products (continued).

Maker	Model	Size	Wt	Record Time	Power Needs	Nom. SNR (dB)	Bandwidth	Dynamic Range	Cost	PC Interface	Stereo/ Mono	Voice Encoding	Sample Freq / Bit Rate
JazPiper	MV32P	66mm x 90mm x 18mm	74g	32MB or 2 hrs (exp to 64MB)	2 AAA (10 hrs play time)	90dB			169.00	Yes			
JazPiper	MVR64P	66mm x 90mm x 18mm	74g	64MB					249.00	Yes			
D-Link	DMP-100	85mm x 62mm x 17.5mm	62g (w/o batt)	Over 120 min Voice	2 AAA, 3V (10 hrs play time)	90dB	20Hz - 20kHz		139.00	Parallel	Mono Voice Record		24kbps - 256kbps
D-Link	DMP-110	89mm x 65mm x 17mm	80g (w/o batt)	Over 120 min Voice	2 AAA, 3V (10 hrs play time)	90dB	20Hz - 20kHz		149.00	USB (12Mbps transfer)	Mono Voice Record		24kbps - 256kbps
D-Link	DMP-120	89mm x 65mm x 17mm	80g (w/o batt)	Over 120 min Voice	2 AAA, 3V (10 hrs play time)	90dB	20Hz - 20kHz		199.00	USB (12Mbps transfer)	Mono Voice Record		24kbps - 256kbps
Pine	D'Music SM-320V	63mm x 85mm x 17.5mm	62g (w/o batt)	135 min Max Voice	2 AAA, 3V (10 hrs play time)	90dB	20Hz - 20kHz		169.99	Parallel	Mono Voice Record	MP3?	24kbps - 256kbps
Samsung	YP-E32 (Yepp32)	65mm x 87mm x 17.2mm	75g (w/o batt)	32MB/128 min	2 AAA, 3V (10 hrs play time)	90dB	20Hz - 20kHz		149.99	Parallel/ USB opt	Mono Voice Record	ADPCM	
Samsung	YP-E64 (Yepp64)	65mm x 87mm x 17.2mm	75g (w/o batt)	64MB/256 min(?)	2 AAA, 3V (10 hrs play time)	90dB	20Hz - 20kHz		229.99	Parallel/ USB opt	Mono Voice Record	ADPCM	
AudioVox	MP3000	3.3" x 2.5" x 0.7"	2 oz	64MB + 64MB MMC	2 AAA (14 hrs record time)				149.99	Parallel			
MINIDISC													
Sony	MZ-R90	3.125" x 2.875" x 0.6875"	3.7 oz (w/o batt)	74min stereo, 148min mono	1 AA (16.5 hr play time) or 1 NH-14WM NiMH (12 hr play time)		20-20kHz		399.95	PCLink opt (USB to Optical Digital Line In); Line Out to PC; Both Real-Time Only	Both	ATRAC	44.1kHz

Table A-1. Commercial Off-The-Shelf (COTS) Audio Recorder Products (rightmost columns) (continued).

Maker	Model	Time/ Date Stamp	Mic Ext/Int	Removable Memory?	Memory Size (MB)	Notes	URL
JazPiper	MV32P			Both	?	MP3 player.	http://www.layer3.org/devices/portables.html
JazPiper	MVR64P			Both	?	Same as MV32P except has 64MB built in, and has FM tuner and "3D Audio".	http://www.layer3.org/devices/portables.html
D-Link	DMP-100		Int	Both, Built in Flash plus Smartmedia Flash slot	32 Int, 16/32 Smartmedia Cards	32 MB built in Flash Memory. Smartmedia slot allows expansion by 32 MB.	http://www.dlink.com/products/DigitalHome/DigitalAudio/
D-Link	DMP-110		Int	Both, Built in Flash plus 3.3V Smartmedia Flash slot	32 Int, 16/32 Smartmedia Cards	32 MB built in Flash Memory. Smartmedia slot allows expansion by 32 MB.	http://www.dlink.com/products/DigitalHome/DigitalAudio/
D-Link	DMP-120		Int	Both, Built in Flash plus 3.3V Smartmedia Flash slot	64 Int, 16/32/54 Smartmedia Cards	64 MB built in Flash Memory. Smartmedia slot allows expansion by 64 MB.	http://www.dlink.com/products/DigitalHome/DigitalAudio/
Pine	D'Music SM-320V	No	Int	Both, Built in Flash plus 3.3V Smartmedia Flash slot	32 Int, 16/32 Smartmedia Cards	Smartmedia slot allows expansion by 32 or 64 MB to 32 MB built in; 10 MHz/8bit CPU	http://www.layer3.org/devices/portables.html
Samsung	YP-E32 (Yepp32)		Int	Both			http://www.layer3.org/devices/portables.html
Samsung	YP-E64 (Yepp64)		Int	Both			http://www.layer3.org/devices/portables.html
AudioVox	MP3000			Both			http://www.layer3.org/devices/portables.html
MINIDISC							
Sony	MZ-R90	Yes	Ext	Minidiscs	74/148 min	Mini-disc player/ recorder.	http://www.sony.com/

Table A-1. Commercial Off-The-Shelf (COTS) Products (continued).

Maker	Model	Size	Wt	Record Time	Power Needs	Nom. SNR (dB)	Bandwidth	Dynamic Range	Cost	PC Interface	Stereo/ Mono	Voice Encoding	Sample Freq / Bit Rate
Sony	MZ-R70	3.1875" x 3" x 1"	4 oz (w/o batt)	74min stereo, 148min mono	1 AA (17 hr play time) or 1 NC-WMAA NiMH (6.5 hr play time)		20-20kHz		279.95	PCLink opt (USB to Optical Digital Line In); Line Out to PC; Both Real-Time Only	Both	ATRAC	44.1kHz
Sony	MZ-R37SP	4.625" x 3.5" x 0.75"	160 g (w/o batt)	74min stereo, 148min mono	2 AA (15.5 hr play time) or 2 NC-WMAA NiMH (12 hr play time)		20-20kHz		229.95	PCLink opt (USB to Optical Digital Line In); Line Out to PC; Both Real-Time Only	Both	ATRAC	44.1kHz
Sony	MZ-B3	5.25" x 1.125" x 3.125"	305 g (w/o batt)	74min stereo, 148min mono	3 AA (6 hr play) or LIP-12 LiIon Recharge (3 hr play time)		20-20kHz		690.00	Line In, Headphone Jack Out Only	Both	ATRAC	44.1kHz
DAT													
Sony	NT2	4.375" x 0.94" x 2.5"	5.75 oz	60 or 120 min per tape	1 AA (5 hr record time) & 1 CR-1220 Li Button	>80dB, Line In	10-14.5kHz	>80dB	1699.95	Line In/Out Only	Stereo	NT Format, LDM-2 Modul	32kHz, 12 bit nonlinear (equiv to 17 bit)

Table A-1. Commercial Off-The-Shelf (COTS) Audio Recorder Products (rightmost columns) (continued).

Maker	Model	Time/ Date Stamp	Mic Ext/Int	Removable Memory?	Memory Size (MB)	Notes	URL
Sony	MZ-R70	No	Ext	Minidiscs	74/148 min	Mini-disc player/ recorder.	http://www.sony.com/
Sony	MZ-R37SP	No	Ext	Minidiscs	74/148 min	Mini-disc player/ recorder.	http://www.sony.com/
Sony	MZ-B3	Yes	Both	Minidiscs	74/148 min	Mini-disc player/ recorder. VOR capable. Built-in Mic.	http://www.sony.com/
DAT							
Sony	NT2	Yes	Ext	Removable Casette Tape	60/120 min	Micro-cassette player, tape speed 6.35mm/sec	http://www.sony.com/

APPENDIX B

SOLID STATE RECORDER COMPONENTS

The following spreadsheet shows the major components used to make a flash based audio recorder. The recorder features a dynamic range approaching 90dB, a bandwidth of 16kHz, and has over 120 minutes of record time. The size of the recorder is dictated largely by the size of the removable compact flash, and by the size of the batteries.

Table B-1. Solid State Recorder Spreadsheet

Target performance (per microcassette benchmark, but no AGC):

dynamic range (dB)	90	implies	16	bits (but, may not get large dynamic ranges)
Bandwidth (kHz)	16	implies	32000	samples/sec
record time (min)	120	implies	3.686E+09	bits of storage
			460.8	Mbytes of FLASH
compression ratio	2	implies	230.4	Mbytes of FLASH
size (square inches surface area)	12.47	up to	half VHS cassette	
cost (dollars)	$70	up to	$500	

Some initial guesses on size, power consumption needed to meet the modified microcassette benchmark

Component	quan	size (sq in)	tot size	current (mA)	tot current	cost ea	tot cost
Microphone (remote, el cond) WM-61A	1	0.742	0.742	0.5	0.5	$ 1.52	$ 1.52
mic holder	1			0	0	$ 0.50	$ 0.50
mic cable (2 feet)	1			0	0	$ 0.41	$ 0.41
mic cable plug				0	0		$ -
mic cable jack	1		0.000	0	0		$ -
mic amp (AD8551ARM in RM8)	1	0.048	0.048	1	1	$ 1.89	$ 1.89
smt resistors (amp,anti alias filt)	3	0.012	0.037	0	0	$ 0.27	$ 0.81
smt caps (amp, anti alias filt)	3	0.008	0.024	0	0	$ 0.42	$ 1.27
24 bit delta sigma (store 16) CS5333	1	0.060	0.060	30	30	$ 4.43	$ 4.43
Prog Logic (XCR3032XL-10CS48C)	1	0.076	0.076	10	10	$ 2.30	$ 2.30
DSP (TMS320VC5502)	1	0.349	0.349	20	20	$ 10.00	$ 10.00
DSP Equiv 3.3V current for 1.5V				22.7	22.7	-	-
start button	1		0.000		0	$ -	$ -
CompactFlash256	1	7.165	7.165	21	21	$102.00	$ 102.00
Flash holder	1		0.000			$ -	$ -
oscillator (ECS3953M-100-B)	1	0.058	0.058		0	$ 2.78	$ 2.78
DC/DC 3.3V (LTC1877EMS8)	1	0.023	0.023		0	$ 2.96	$ 2.96
DC/DC 1.5V (LTC1877EMS8)	1	0.023	0.023		0	$ 2.96	$ 2.96
battery holder	1		0.000		0	$ 0.70	$ 0.70
battery (AAA Alkaline)	3	0.656	1.969	1150mAh		$ 0.70	$ 2.10
			9.831		105.2273		$ 136.64
			excldg mic				

APPENDIX C

BODY WIRE PRODUCT SOURCE MATRIX

COMPANY NAME	STREET ADDRESS	PHONE	FAX	EMAIL	(M) Mfr (D) Distrb (N) NATIA	PRODUCT
Accuquest Corporation	P.O. Box 704 Hunt Valley, MD 21030	410-584-2355	410-584-2356		N	
AMC Sales	193 Vacquero Dr. Boulder, CO 80303	303-499-5405	800-926-2488		D	mini microphone
Audio Intelligence Devices, Inc.	12301 NW 39th St. Coral Springs, FL 33065	954-255-2619		donna.eagle@waida.com	N	narrow band transmitters
Bugs & Things	UK	44-0-116-2470606	44-0-116-2470604	www.ukinternet-marketing.co.uk/bugsnthings	D	mini microphone
CCS International						
Counter Spy Shop	Rotterdam		31-10-290-9688	www.counterspyshop.com	D	pen transmitter
Datong Electronics Limited	Clayton Wood Close, West Park Leeds, UK LS166QE	44 113 2744 822			N	
DTC Communications, Inc.	75 Northeastern Blvd. Nashua, NH 3062	603-880-4411	603-880-6965	www.dtccom.com http://www.epgctac.com/audio.htm	N	audio transmission equipment
Global Microwave Systems	4141 Avenida de la Plata Oceaside, CA 92056	760-631-8021	760-631-8031	gms.gmsinc.com	N	miniature surveillance equip.
Harris Corporation	P. O. Box 37 Melbourne, FL 32902	407-727-6079			N	
Innovative Surveillance Technology	11840 N.W. 41st Street Coral Springs, FL 33065	954-755-0724	954-755-0817	teamist@aol.com	N	audio surveillance equip.

Intelligence Support Group, Lt.	various locations	760-377-5013	760-377-5073	from site onlu	M	surveillance equip.
ISIS Surveillance Sytems and Equipment Co, Inc.	P.O. Box 577 Tyler, TX 75710	903-533-1712	903-533-1713		N	body worn surveillance systems
Law Enforcement Associates	100A Hunter Place Youngsville, NC 27596	919-554-4700	919-556-6240	lea2@mindspring.com	N	audio surveillance systems
M3 Media Consultants, Inc.	P. O. Box 510567 Punta Gorda, FL 33951	941-575-7007	941-575-2727	m3papy@aol.com	N	covert surveillance audio equip.
Premier Wireless, Inc.	4749-C Bennett Drive Livemore, CA 94550	925-449-2101	925-449-9148		N	body worn transmitters
Probity Electronics Inc.	574 Meacham Ave. Elmont, NY 11003	516-775-3275	516-355-0225	probityelec@hotmail.com	N,M,D	body transmitters
Schell Electronics, Inc.	120 N. Lincoln Chanute, KS 66720	316-431-2350	316-431-2365	www.chanuteks.com/schell	N,M,D	surveillance transmitters
Security Research Ltd.	Corby Road, Weldon Corby, Northants, UK NN173AR	44 1536400988	44 1536266711	marketing@security-research.com	N,M,D	surveillance equipment
Special Electronic Security Products, Ltd.						
Spectronic Systems	3389 Sheridan St., Suite 156 Hollywood, FL 33021	954-359-9847	954-359-9857	radome1494@aol.com	NMD	hardwire audio systems
Spy City		1-888-Spy-City			D	body transmitters
Spy Equipment Store		877-779-0007 403-237-8130			D	body transmitters
SpyZone						
Swintek, Inc.	965 Shulman Ave. Santa Clara, CA 95050	408-727-4889	408-727-3025		N,M	covert transmitters

Name	Address	Phone	Fax	Email/Web		Products
Systems Wireless, Ltd.	465 Herndon Pkwy. Herndon, VA 20170	703-471-7887	703-437-1107			
Tactical Technologies, Inc.	1701 Second Ave. Folsom, PA 19033	610-522-0106	610-522-9430	rsnyder459@aol.com	N,M	body wires
Tektron Micro Electronics, Inc.	7483 B Candlewood Rd. Hanover, MD 21076	410-850-4200	410-850-4209	tmei@erols.com	N,M	digital stereo audio equipment
Teletron Ltd.	6 Halapid St. Petack				M	mini transmitter
The Global Spy Shops	various locations			globalspy.com	D	pen microphone
The Spy Shop				from site only	M	mini microphone
The Spy Store	2627 West Railway St. Abbosford, BC V2S2E6	604-859-4769	604-859-2799		D	pen microphone
Audio Visual Security Ltd.	64 Granville Park, Blacrock Co. Dublin Ireland	353-0-1287-0055	353-0-1287-0056	alan@avsecurity.com	M	mini transmitter
Employers Asset Protection	Raleigh, NC	888-340-5874	919-250-1998	www.eaprotection.com	M	micro-pen
Bull Electrical	250 Portland Road Hove Sussex, UK BN35QT	44-0-870-7404635	44-0-1273-323077	www.bullnet.co.uk	D	mini transmitter
Kubies Electronics	P.O. Box 8681 Lexington, KY 40533			electronicsabc@mindspring.com	D	mini mic
The Spy Connection	5023 Camp Bowie Blv. Ft. Worth, TX 76107	877-779-2666		www.thespyconnection.com	D	mini mics (tie clip)
Spygate	3811 Schaefer Ave. Ste. I Chino, CA 91710	909-517-1107	909-517-1105	sales@spygate.com	M,D	mini mic
E-Spyzone (part of CCS Int'l)	360 Madison Ave. 6 FL New York, NY 10017	212-557-3040	212-983-1316	information@e-spyzone.com	D	pen, mini mic
Lorraine Electronics Surveillance	716 Lea Bridge Road London, UK E106AW	44-0-20-8558-4226	44-0-20-8558-1338	salesinfo@lorraine.co.uk	M	pen mic, mini trx

63

Name	Address	Phone	Fax	Email/Web		Products
Spy Supply Online				www.spysupplyonline.com	D	mini microphone, pen
Spy Tech Agency	8519-8521 W. Sunset Blvd. W Hollywood, CA 90069	310-657-6333	310-657-8714		D	surveillance mics
Cyber Gold (Golden West Investigative Group, Ltd.)	41527-923, 12th Street New Westminster, BC Canada V3M1K0	604-318-8545	604-521-4085	www.cyber-gold.com	D	mini microphone
Spymaster Advanced Intelligence Co. Ltd.		972-8-936-2304	same	gmelnick@spymaster.co.il	D	body wire trx.
SpyMarketplace	USA Online Services, Inc. 2500 Old Alabama Rd. Roswell, GA 30076	800-490-2723	770-640-6752	spy@spymarketplace.com	D	mini microphone
Spy Surplus		800-269-0718	818-475-5330	www.spysurplus.com	D	body wires, pen mic
Micro Electrical				www.microelec.com	M	pen mic
Audiotel International Ltd.	Cavendish Courtyard, Sallow Road Corby, England NN175DZ	01536-26-66-77	01536-26-67-11			
IBH-IMPEX ELEKTRONIK GMBH	Friederikenplatz 55 Dessau 6844	0340-240-02-42	0340-240-02-44			
ATET Telematica radiotelecomunicazioni	V.G. da Verrazzano 42 Torino, Italy 10129	39-011-56-83-200	39-011-59-04-93	info@atet.it		
Elvira Production Firm	Gidrogorodok, Korpus A Moscow Region, Zheleznotorozhny, Russia 143980	7-095-5227691	same	firm_elvira@hotmail.com		
JSC "Grant - Systems & Technologies "	Parkovaya 9th Str 53 Moscow, Russia 105215	464-04-81	same	gstech@cityline.ru		

PK Electronic International	Security Search Product Sales - P.O. Box 14237 Denver, CO 14237	303-233-7854				
Twitco Distributing	PO Box 239 Rindge, NH 03461	603-899-9800	603-899-9802	ewp@twitco.com http://www.mv.com/ipusers/twitco/	D	Earphones, Microphones, Covert shrouds, Headsets, Tactical Equipment
Covert-Systems.com By Ross Associates	2495 Vista Drive Upland CA 91784	909-981-8855	909-981-7386	sales@covert-systems.com http://www.ross.cc/index.html	D	

APPENDIX D

SOLID STATE RECORDER AND BODY WIRE SURVEY RESULTS

The following tables contain the results of a survey submitted to a cross section of US law enforcement agencies. The populations served by these agencies range from less than 1,000 to over 1,000,000. The locations of these agencies are all across the continental United States. 77 responses were received from the survey. The survey asked a number of questions regarding the typical use of recorders and body wires for law enforcement applications. The answers to these questions are summarized in the tables below.

Table D-1. Body Worn Recorder Survey Responses.
Our department uses body worn voice recorders on average _____ days a month.

Survey #		Survey #				
1				41	n/a	
2	10			42	n/a	
3				43	5	
4	1			44	20	
5	0			45		
6				46	0	
7				47	30	
8				48		
9	8			49		
10	30			50		
11	10			51	22	
12	1			52	0	
13	1			53	6	
14	0			54	0	
15	20			55	0	
16	20			56		
17	0			57	1	
18	0			58	0	
19				59		
20	0			60	1	
21	1			61	0	
22				62	30	
23	0			63		
24				64		
25				65	0	
26	15			66	0	
27				67	0	
28				68	0	
29				69	10	
30				70	1	
31	3			71		
32				72	1	
33				73	n/a	
34				74	0	
35	1			75	20	
36	30			76		
37	2			77	0	
38	0.5					
39	?					
40						

<u>Our department uses body worn voice recorders for the following types of operations.</u>

Survey #				
1				
2	Officer buys (backup)	Informant Buys (backup)		
3				
4	Crimes against person	Drug Offenses	arson	Property Crime
5				
6				
7				
8				
9	Narcotics	Robbery/Homicide	Burglary Investigation	Sexual Assault
10	Narcotics	Prostittution	Intelligence Gathering	
11	Drugs			
12	Drug Buys	Alcohol Buys		
13	Felonies	Any Drug Cases		
14	Drug Investigations			
15	Narcotic Buys	Prostitution		
16	Undercover			
17				
18	Narcotics	Personal Crimes		
19				
20				
21	drugs	Robbery/Homicide		
22				
23				
24	interviews	Traffic Stops		
25				
26				
27				
28				
29				
30				
31	Drug Case	Prostitution Cases		
32				
33				
34	Drugs	Intel Work		
35	Narcotics	Vice		
36	Narcotics	Gambling	Prostitution	
37	Narcotics	Gambling	Integrity	White Collar
38	Major Crimes			
39	Intelligence	Demo		
40				
41				
42				
43	Narcotics			
44	Traffic Stops	Callout Response	Impromptu Telephone Monitor	
45				
46				
47	Officer Protection	Interview/Investigation	Investigate Officer Complaints	Court Purposes
48				
49				
50				

51	CI Drug Purchases	U/C Drug Purchases	Intelligence Gathering	Assist CID
52				
53	Undercover Drug Operations			
54	n/a			
55		0		
56				
57	Drug Investigations	Stolen Property		
58				
59				
60	Intelligence Gathering			
61				
62	Patrol	Interviewing		
63				
64				
65	Narcotics			
66				
67	n/a			
68				
69	Narc	other		
70	Narcotics	guns	Assaults	
71				
72	Drugs	Burglary / theft	Sexual Crimes	Threat Complaints
73				
74				
75	Undercover	Drug Investigations		
76				
77	n/a			

Our department owns _____ body worn voice recorders.

Survey #		Survey #	
1		41	
2	4	42	
3		43	2
4	1	44	5
5	0	45	
6		46	1
7		47	6
8		48	
9	1	49	
10	20	50	
11	1	51	12
12	1	52	0
13	1	53	1
14	1	54	0
15	12	55	
16	6	56	
17		57	2
18		58	2
19		59	
20		60	2
21	1	61	
22		62	40
23		63	
24	7	64	
25		65	0
26	0	66	
27		67	0
28		68	
29		69	6
30		70	2
31	1	71	
32		72	1
33		73	
34		74	
35	3	75	20
36	4	76	
37	2	77	2
38	0		
39	1		
40			

We require a minimum recording time of ___ minutes per use or ___ hours per operation.

Survey #	Minutes	Hours	Survey #	Minutes	Hours
1			41		
2	60		42		
3			43	60	1
4	60		44	don't require	
5			45		
6			46		
7			47	All contacts on assigned shift	
8			48		
9	90	2	49		
10		2	50		
11	60	1	51	90	3.5
12	60	60	52		
13			53	90	8
14			54		
15	90		55		
16	n/a		56		
17			57		
18			58		2
19			59		
20			60	90	
21	90		61		
22			62	60	
23			63		
24	n/a	n/a	64		
25			65		
26			66		
27			67		
28			68		
29			69	60	
30			70	60	
31	90	1.5	71		
32			72	60	1
33			73		
34			74		
35			75		
36	120	2	76		
37	120		77	none set	
38					
39		1			
40					

71

Our Department stores the recordings for (days\weeks\months\years)

Survey #	Days	Weeks	Months	Years	Survey #	Days	Weeks	Months	Years
1					41				
2				5	42				
3					43				x
4				forever	44				1
5					45				
6					46				
7					47				case by case basis
8					48				
9				2	49				
10				Trial/Appeals	50				
11				As Long as Needed	51				5
12		x			52				
13			x	x	53				10
14			x		54				
15				Till case is over	55				
16				x	56				
17					57				7
18				5	58				until case is tried
19					59				
20					60				1
21				5	61				
22					62				depends on situation
23					63				
24				3	64				
25				1	65				
26					66				
27					67				
28					68				
29					69				x
30					70				
31					71				
32					72			x	
33					73				
34					74				
35				indefinite	75				x
36					76				
37					77				
38	90								
39				1					
40									

Our Voice Recorders are (mini-casstte) (solid state) type

Survey #	Mini Cassette	Solid State	Survey #	Mini Cassette	Solid State
1			41		
2	x		42		
3			43	x	
4	x		44	x	
5			45		
6			46		
7			47	x	
8			48		
9			49		
10	x	Digital	50		
11	x		51	x	I Wish
12		x	52		
13	x		53	x	
14	x	x	54		
15	x		55		
16		yes	56		
17			57	x	
18	x		58	x	
19			59		
20			60	x	
21	x		61		
22			62	x	
23	x		63		
24	x		64		
25	x		65		
26			66		
27			67		
28			68		
29			69	x	x
30			70	x	
31	x		71		
32			72	x	
33			73		
34	x	x	74		
35		x	75	x	
36	x		76		
37	x		77	x	
38					
39		x			
40					

We use Voice Recorders for:

Survey #	Officer Protection	Intelligence Gathering	Testimony Support	Survey #	Officer Protection	Intelligence Gathering	Testimony Support
1				41			
2	y	y	y	42			
3				43	y	y	y
4	y	y	y	44	y	y	y
5				45			
6				46			
7				47	y	y	y
8				48			
9				49			
10		y	y	50			
11	y	y	y	51	n	y	y
12	y	y		52			
13	y	y	y	53	y	y	y
14	y	y	y	54			
15	y	y	y	55			
16	y	y	y	56			
17				57			
18	y	y	y	58	n	y	y
19				59			
20				60	n	y	y
21	y	y	y	61			
22				62	y	y	y
23		y	y	63			
24	y	y	y	64			
25			y	65			
26				66			
27				67			
28				68			
29				69		y	y
30				70	n	y	y
31	y	y	y	71			
32				72	y	y	y
33				73			
34	y	y	y	74			
35	y	y	y	75		y	y
36	y	y	y	76			
37	n	y	y	77		y	y
38							
39	y	y	y				
40							

74

Our Voice Recorders are:

Survey #	Dept Issued	Personal Purchase	Survey #	Dept Issued	Personal Purchase
1			41		
2	x		42		
3			43	x	
4	x		44	x	
5			45		
6			46		
7			47	x	
8			48		
9	x	x	49		
10	x		50		
11	x		51	x	
12	x		52		
13	x		53		x
14	x		54		
15	x		55		
16	x		56		
17			57	x	
18	x		58	x	
19			59		
20			60	x	
21	x		61		
22			62	x	x
23		x	63		
24	x		64		
25		x	65		
26			66		
27			67		
28			68		
29			69	x	x
30			70	x	
31	x		71		
32			72		
33			73		
34	x		74		
35	x		75	x	
36	x		76		
37	x		77	x	
38					
39	x				
40					

Please rank the following items from 1-8 (1 most imprtant)

Survey #	Size	Record Time	Battery Life	Packaging	Mike Sensitivity	Cost	Voice Operated	Operating Controls
1								
2	5	1	7	4	2	8	6	3
3								
4	4	3	7	1	2	8	5	6
5								
6								
7								
8								
9	2	4	5	1	2	4	6	5
10	1	3	5	2	4	7	8	6
11	4	7	8	1	2	5	3	6
12	1	3	5	7	4	8	2	6
13	5	3	4	2	1	8	7	6
14	1	2	3	8	4	5	7	6
15	1	2	3	8	8	6	7	4
16	1	3	6	2	4	8	5	7
17								
18								
19								
20								
21	2	1	3	6	5	4	8	7
22								
23			2		3	1		
24	3	6	7	8	5	1	5	4
25	1	2	8	7	3	5	6	4
26								
27								
28								
29								
30								
31	1	6	4	3	2	7	8	5
32								
33								
34	1	3	5	2	4	6	7	8
35	1	3	5	2	6	4	8	7
36	4	3	2	5	7	6	8	7
37	1	2	6	4	5	3	7	8
38								
39	1	7	6	4	2	5	3	8
40								
41								
42								
43	8	8	8	8	8	8	1	8
44	6	8	5	7	4	3	2	1
45								
46								
47	6	5	3	7	2	4	8	1
48								

49								
50								
51	4	5	1	3	2	8	7	6
52	1	3	2	4	5	7	8	6
53	1	2	3	4	5	7	8	6
54								
55								
56								
57	1	5	7	3	2	4	8	6
58	3	1	2	4	7	5	8	6
59								
60	3	6	5	2	1	8	4	7
61								
62	1	6	7	3	2	4	8	5
63								
64								
65								
66								
67								
68								
69	4	1	3	5	2	7	8	6
70	4	7	6	3	1	8	5	2
71								
72	1	2	2	1	1	2	2	2
73								
74								
75	2	3	4	1	7	6	8	5
76								
77	3	5	8	1	2	7	6	4

The courts in our area (allow) (don't allow) voice recording of ofcr interviews as evidence.

Survey #	Allow	Don't Allow	Survey #	Allow	Don't Allow
1			41		
2	x		42		
3			43	x	
4	x		44	x	
5			45		
6			46		
7			47	x	
8			48		
9	x		49		
10	x		50		
11	x		51	x	
12	x		52	x	
13	x		53	x	
14			54		
15	x		55		
16			56		
17			57	x	
18	x		58	x	
19			59		
20			60	x	
21	x		61		
22			62	x	
23	x		63		
24			64		
25	x		65		
26			66		
27			67		
28			68		
29			69	x	
30			70	x	
31	x		71		
32			72	x	
33			73		
34	x		74		
35	x		75	x	
36	x		76		
37	x		77	x	
38					
39	x				
40					

What improvement would you like to see in your current voice recorders?

Survey #	
1	
2	Mike sensitivity - quality & operating controls
3	
4	
5	
6	
7	
8	
9	Concealment
10	Digital recorders offer best convenience, size, and clarity
11	
12	
13	More recording time and better mic sensitivity,
14	
15	
16	Size, Voice operated mike sensitivity
17	
18	
19	
20	I prefer concealed wire of greater ouput power and increased range to use of "pager" style wires. Although the pager/wire/xmtrs are great for officer saftey vis-a -vis discovery, they really provide a poor/fluctuating signal-which can also compromise saftey and limits evidencing value.
21	Voice quality - voice freq improvement
22	
23	
24	lower cost for better units
25	Ability to reduce or eliminate motor noise in recording/playback
26	
27	
28	
29	
30	
31	ability to record without mic having to be at neck level
32	
33	
34	
35	
36	Smaller, better mic
37	
38	
39	cost
40	
41	
42	
43	Smaller, more concealable
44	Clarity, Reliability (sturdiness)
45	
46	
47	ease of one touch controls, recording quality & time. Size of unit.

48
49
50
51   Be Digital
52
53   Longer recording time. Better Recordings. Digital Recorders.
54
55
56
57
58   I would like the recorders to be easier to conceal
59
60   n/a
61
62
63
64
65
66
67
68
69
70
71
72   easy concealment, clarity
73
74
75   Size
76
77   would like to see full range of products & how they can be used in the field.
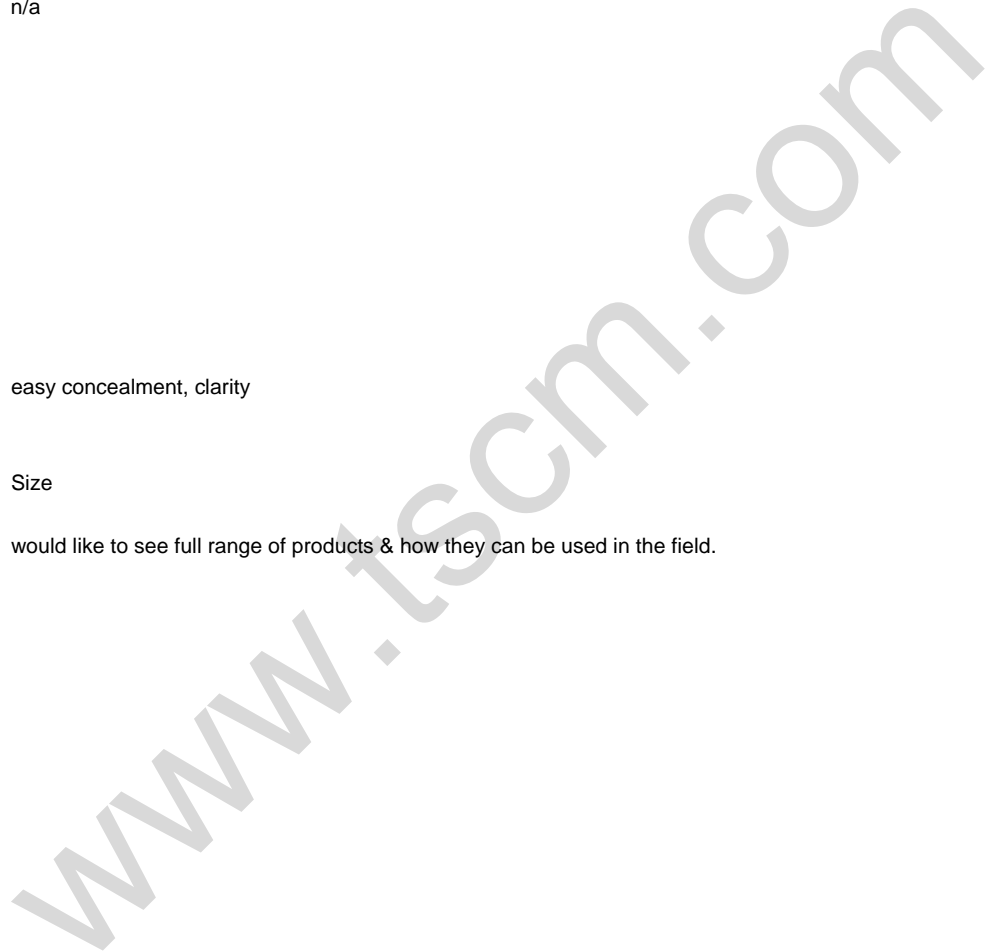
COMMENTS

Survey #

1 The body wire/repeater/recorder that we currently use is ver user friendly. Has many features and the recordigs are clear and easily understood.

2

3 We can no longer use the traditioinal wire transmitters because of RF Detectors and scanner technology. We now use digital recorders. It would be useful to have an emergency transmitter only.

4

5

6

7

8 Currently our department does not own or use a body worn transmitter or recorder. However we are interested in obtaining additional information for possibly future purchases.

9

10

11

12

13

14

15

16

17

18

19

20

21

22

23 My department has two bike patrol officers. I would be interested in info on the new technology you have available. Durability is a primary concern along with comfort and sensitivity. A follow up from your company would be appreciated. B.H.

24

25

26 Question #1 Reflects use of concealed narcotics use. Question #3 7 of 10 units are used in video/audio in patrol units. 3 units are for undercover use.

27 We use the mics from our mobile vision camera system everyday for everything. Officers keep a recorder record of every contact with public. (We go through 1 video tape per officer per day) Peole do not know a record is being kept. It works well for all purposes.

28

29

30

31

32

33

34 Dream: To have equipment that always works.

35

36

37

38

39 Thank you for the opportunity to complete this survey.

40 Our department only uses body wires on rare occassions and all operations and equipment are conducted and maintained by the Bucks Co. District Attorneys Office County Detective Bureau.

81

41

42

43

44

45

46

47

48   We do not own body worn recorders. Thank you for your concern with our needs. Sgt Martin.

49

50

51   We are in the process of converting to all digital equipment. There is not enough digital body wire/ recorder reciever equipment to choose from. Further we are looking for a reliable, clear, comparable range to body wire, body worn video transmitters.

52   We currently do not use body worn recorders, but is an option that is being looked into.

53

54

55

56

57

58

59

60

61

62

63

64   We are not allowed to use body wires in the state of Oregon as this time.

65

66   We have used in car video camera mikes on several occasions. Sound seems to be very clear and units are dependable. I have had problems with our wires cutting in and out on numerous occasions. Seems like when the antenna gets a kink or twist in it, cuts out sound. Range is very poor.

67

68   Hopefully I did not misunderstand the questionnaire. We use body worn transmitters daily in patrol section. Covert usage involves borrowing equipment. We do not own and use infrequently. Most officers rely on body transmitters; few use personal micro-cassette recorders in addition. Please call if you need further.

69

70

71   Our department primarily uses covert communications devices for steak-outs conducted in the field. These devices are compatible with our current "hand held" Motorola Saber radios.

72   We are currently looking to purchase new equipment since ours is outdated. I am now looking to compare different styles and prices. I would greatly appreciate any assistance you can offer. I don't know if you have info on this or any grants that would help purchase better equipment. Thanks in advance.

73

74

75

76   The Greenwich PD used to have operable video cameras and body wires in two patrol cars. The equipment became obsolete and out-dated and is no longer used. Although, in the future we would like to acquire new cameras.

77

Table D-2. Body Worn Transmitter Survey Responses.

Average use of body wires per month.

Survey #		Survey #	
1	8	41	72
2	30	42	20
3	0	43	25
4	1	44	2
5	6	45	0
6	1	46	10
7	0	47	n/a
8	0	48	10
9	8	49	
10	60	50	1
11	10	51	32
12	1	52	5
13	1	53	
14	15	54	0
15	20	55	
16	20	56	8
17	8	57	1
18		58	30
19	8	59	3
20	2	60	12
21	1	61	0
22	1	62	20
23	16	63	2
24	0	64	0
25	20	65	10
26	10	66	3
27	31	67	2
28		68	1 Undercover use everyday
29		69	30
30	1	70	30
31	15	71	
32	14	72	2
33		73	1
34	Very Often	74	2
35	6	75	50
36	30	76	n/a
37	8	77	2
38	5		
39	?		
40			

84

Our department uses body worn voice recorders for the following types of operations.

Survey #

#				
1	Illegal Narcotics	Delivery Stings	Gather Info	
2	Officer Buys	Officer Buy/Bust	Informant buys	Informant buy/bust
3	Narcotics Crimes	Serious Felonies		
4	Crimes against Persons	Drug Offenses	Arson	Property Crimes
5	Narcotics	Stolen Property		
6				
7				
8	n/a			
9	Narcotics	Burglary Investigations	Homicide Invest	Sexual Assault Invest
10	Narcotics	Prostitution	Money Laundering	Informants in other crimes
11	Drug	Alcohol Stings		
12	Drugs	Alcohol		
13	Felonies	Drug Cases		
14	Drug Investigations	Prostitution		
15	Narcotics Buys	Prostitution		
16	Undercover			
17	Drug investigations			
18	Narcotics	Personal Crimes	Prostitution	Property Crimes
19	Narcotics	Major Crimes		
20	Narcotics			
21	Drug	Robbery		
22	Drug	Alcohol Compliance	Other Criminal	
23	Bike Patrol	Tavern Walk Thru	Narcotics Surveillance	
24	n/a			
25	Drunk Driving Stops			
26	Narcotics	Patrol/Criminal Patrol	Invest Interviews	
27	General Patrol	Domestic Abuse	Assault	Crime Invest
28				
29				
30	Narcotics Purchase	Officer Protection		
31	Drug Cases	Prostitution		
32	Narcotics	Burglary/Stolen Property	Sex Crimes	
33				
34	Drugs	Intel work		
35	Narcotics	Vice		
36	Narcotics	Prostitution	Gambling	
37	Narcotics	Gambling		
38	Major Crimes	Robberies	Burglary	
39	Survey	Demo	Intellig gathering	
40				
41	Narcotics			
42	Narcotics	Stings	Informants	
43	Narcotics			
44	Drug Invest	Sex Crimes	Inmate Contacts	Property Crimes
45				
46	Undercover Narcotics	Prostitution	Vice	
47				
48	Drug Operations	Sexual Assault	Sexual Abuse Minor	Burglary/Theft
49				
50	Drug			

84

85

51	CI Drug Purchase	U/C Drug Purchaces	Homicide Invest	CID Investigation
52	Drugs	Burglary	Vice	
53	Drugs	Stolen Property		
54	n/a			
55	Traffic Stop	DWI/DUI Enforcement	Domestics	
56	Narcotics			
57	Drug Investigations	Stolen Property		
58	Drug Investigations	Buying illegal weapons	Murder Investigations	
59	Narcotics	Thefts	Burglaries	Forgeries
60	Undercover Drug Buys	Informant Drug Buys	Prostitution Stings	
61				
62	Drug Investigations	Sexual Abuse of Minors	Sexual Assault	
63	Drug	Property Crimes		
64				
65	Narcotics Invest			
66	Drug Buys	Hotel Room Surveillance	Gathering Information	Prostitution Invest
67	Drug Investigations			
68	Narcotics	Patrol		
69	Narcotics	Other		
70	UC Drug Purchase	UC Gun Purchases	Officer Safety	
71				
72	Drugs	Theft	Sexual Crime	Threat Complaints
73	Narcotics	Vice		
74	U/C Buys	CI Buys	Officer Safety	
75	Drug Investigation	Criminal Invest		
76	N/a			
77	Narcotics	Fraud	Vice	

Our department owns _____ body wires.

Survey #		Survey #	
1	2	41	12
2	6	42	9
3	1	43	2
4	1	44	2
5	1	45	
6	1	46	3
7		47	
8	0	48	1
9	3	49	
10	28	50	0
11	1	51	6
12	1	52	11
13	1	53	1
14	4	54	0
15	8	55	2
16	8	56	3
17	3	57	
18		58	3
19	2	59	2
20	2	60	6
21	2	61	
22	0	62	1
23	1	63	2
24	0	64	0
25	2	65	2
26	10	66	3
27	2	67	2
28		68	5
29		69	12
30	2	70	2
31	3	71	
32	2	72	1
33		73	0
34	2	74	2
35	4	75	5
36	4	76	0
37	3	77	1
38	0		
39	?		
40			

86

On occasion we borrow body wires Y/N.

Survey #	Other Local Department	State Agency	Federal Agency	Survey #	Other Local Department	State Agency	Federal Agency
1	n	n	y	41	n	n	n
2	n	n	n	42	n	n	n
3	n	n	y	43	n		
4		y		44	y	y	n
5	y	y	n	45			
6	y	n	n	46	y	n	n
7				47			
8	n	n	n	48	n	y	n
9	n	y	y	49			
10	n	n	y	50		y	
11	y	y		51	n	n	n
12	n	n	n	52	n	n	n
13		y	y	53	n	n	n
14	n	n	n	54	n	n	n
15	n	n	n	55	y	y	y
16	n	n	n	56	n	n	n
17	n	n	n	57	y		
18	n	n	n	58	n	n	n
19	y	y	y	59	n	n	n
20	n	n	n	60	n	n	n
21	n	n	n	61			
22	y			62	n	y	n
23	n	n	n	63	y	y	y
24	n	n	n	64	n	n	n
25	n	n	n	65	n	y	y
26		y	y	66	n	n	n
27				67	n	n	n
28				68	y	y	n
29	n	n	n	69	n	n	n
30	n	y	y	70	n	n	n
31			y	71			
32	n	n	n	72	n	n	n
33				73	y	y	
34		y		74	n	y	y
35	n	n	n	75	n	n	n
36	y	y	y	76	n	n	n
37	y	y	n	77	n	y	n
38	y						
39							
40							

We obtain our equipment:

Survey #	Dept Purchase	State Agency Purchase	Procurement Cooperative	Loan from State/Fed Agency	Other	Survey #	Dept Purchase	State Agency Purchase	Procurement Cooperative	Loan from State/Fed Agency	Other
1	x					41		x			
2	x					42	x				
3	x				HIDTA	43	x				
4	x					44	x				
5	x					45					
6	x					46	x				
7						47					
8	x					48	x				
9	x	x	x	x		49					
10	x		x			50				x	
11	x				x	51	x		x		
12		x				52					GRANTS
13	x					53	x				
14	x					54	x				
15	x		x			55	x				
16	x					56	x				
17	x					57				x	
18	x					58	x				
19	x		x			59	x				
20	x					60	x				
21	x	x				61					
22					x	62	x				
23	x					63	x				
24	x					64					
25	x					65	x				GRANTS
26	x					66	x				
27	x					67	x				
28						68	x	x		x	
29						69	x				
30	x					70	x				
31	x					71					
32	x			x		72	x				
33						73			x		
34	x					74	x				
35	x				x	75	x				
36	x					76					
37	x					77	x			x	
38											
39	x										
40											

88

Our Department uses body wires that operate (y/n)

Survey #	VHF	UHF	GHZ	Spread Spectrum	Survey #	VHF	UHF	GHZ	Spread Spectrum
1	y				41	y	n	n	n
2	y	n	n	n	42	y	n	n	n
3	y				43				
4	y	n		n	44	y			
5	y	n	n	n	45				
6	y	n	n	n	46	y	y	n	n
7					47				
8					48	y	n	n	n
9	y	y			49				
10	y	y	y	n	50				
11	y				51	y	n	n	n
12					52	y	n	n	n
13	n	y	n	n	53	y			
14					54				
15	y	n	n	n	55	y			
16					56	y	n	n	n
17	y	n	n	n	57	y			
18	y	y	n	n	58	y			
19	y				59	y	n	n	n
20	y				60	n	y	n	n
21	y				61				
22					62	y	n	n	n
23	y	n	n	n	63		y		
24					64				
25	y				65				
26					66	y	n	n	n
27	y	n	n	n	67	y	n	n	n
28					68	n	y	n	n
29					69	y	n	y	n
30					70	y	n	n	n
31	n	n	n	n	71				
32	y				72	y	n	n	n
33					73	y			
34		y			74				
35	y	n	n	n	75	n	y	n	n
36	n	n	y	n	76				
37	y	n	n	n	77				
38	y								
39									
40									

<u>Our Department owns body wires manufactured by the following companies:</u>

Survey #			Survey #	
1	Tactical Technologies	AID	41	
2	AID	LEA	42	Motorola, LEA, AID
3	Unkown		43	AID
4	AID / Westinghouse		44	
5	AID		45	
6	AID / Westinghouse		46	
7			47	
8	n/a		48	AID & Westinghouse
9	AID	LEA	49	
10	AID		50	
11	Law Enforcement Associates		51	AID & TTI
12			52	AID
13			53	AID
14	AID, LEA		54	N/A
15			55	TELEX
16	AID		56	
17	AID		57	
18	Unkown		58	TTI
19	LEA, AID		59	LEA
20	AID		60	AID TELEX
21	Tactical Technologies		61	
22	n/a		62	TTI
23	Parmarlow		63	AID
24	n/a		64	
25			65	Dynatech
26	TEA		66	LEA
27	Mobile Vision		67	TTI, LEA
28			68	Mobile Vision
29			69	AID, LEA
30			70	DTC
31	AID		71	
32	AID		72	LEA
33			73	
34			74	
35	TTI and AID		75	AID
36	ProTech		76	
37	AID and TTI		77	
38	Unkown			
39	?			
40				

When our body wires need repair we:

Survey #	In-House Repair	Return to Manufacturer	Send to Local Radio Shop	Other	Survey #	In-House Repair	Return to Manufacturer	Send to Local Radio Shop	Other
1		x			41		x		
2		x			42	x	x		
3		x			43		x		
4		x			44			x	
5		x			45				
6		x			46		x		
7					47				
8					48		x		
9		x			49				
10		x			50				
11		x			51	x	x		
12		x			52		x		
13		x			53		x		
14		x			54				N/A
15		x			55		DEALER		
16		x			56		x		
17		x			57		x		
18	x	x			58		x		
19		x			59		x		
20		x			60		x		
21		x			61				
22		x			62	x	x		
23		x			63		x		
24				N/A	64	x			
25		x			65		x		
26		x	x		66			x	
27		x			67		x		
28					68		x	x	
29					69	x	x		
30		x			70		x		
31		x			71				
32	x				72			x	
33					73		x		
34		x			74			x	
35		x			75		x		
36		x			76				
37	x	x			77		x		
38		x							
39		x							
40									

Please Rank the following items from 1-10 (1 most important)

Survey #	Size	Range	Battery Life	Tx Freq	Mike Sensitivity	Built in Recorder	Cost	Encryption	Audio Adjustment	Packaging
1	8	2	5	3	1	6	10	7	4	9
2	5	1	3	10	2	7	6	9	8	4
3	3	4	4	3	2	8	4	1	6	2
4	3	5	6	10	1	4	7	9	8	2
5	2	4	7	5	3	10	6	8	9	1
6	2				1		4			3
7										
8										
9	2	4	5	7	6	10	5	8	8	3
10	1	3	5	9	4	6	10	8	7	2
11	5	1	7	6	3	9	4	10	8	2
12	5	4	6	10	2	8	3	9	7	1
13	4	2	6	9	1	7	10	8	5	3
14	1	2	5	4	6	8	3	7	9	10
15	1	2	4	7	6	9	3	8	10	5
16	1	2	4	9	5	8	10	6	7	3
17	1	3	4	10	6	8	5	7	9	2
18	1	4	7	5	3	6	2	9	8	10
19	6	2	3	8	1	10	7	5	9	4
20	2	1	4	8	3	10	7	9	6	5
21	3	1	2	6	4	7	5	9	10	8
22	1	2	10	6	3	8	5	7	9	4
23	3				1		6			2
24										
25	4	5	2	9	6	7	1	8	3	10
26	2	3	7	9	6	8	1	10	4	5
27	2	4			5		1			3
28										
29										
30	1	2	8	10	4	9	3	7	6	5
31	2	1	6	7	5	8	3	9	10	4
32	4	1	5	7	2	9	6	8	10	3
33										
34	1	2	6	10	3	8	4	9	7	5
35	1	5	7	2	6	9	4	10	8	3
36	2	1	5	6	4	9	5	7	8	3
37	1	2	4	7	6	9	5	10	8	3
38										
39	1	3	9	6	2	4	5	7	8	10
40										
41	2	5	4	7	3	8	6	9	10	1
42	3	2	4	6	5	9	8	7	10	1
43	8	8	5	8	8	1	8	1	5	8
44	5	2	6	8	3	7	4	9	10	1
45										
46	7	2	4	1	3	10	9	6	5	8
47										
48	1	2	8	5	6	10	4	3	9	7
49										

92

50	6	2	8		3	5	1	4	9	7
51	4	2	1	7	3	10	9	8	6	5
52	2	3	5	9	6	7	8	4	10	1
53	1	2	4	7	3	8	10	5	9	6
54										
55	4	2	6	5	1	10	3	7	8	9
56	7	1	2	10	4	8	6	5	9	3
57	1	4	7	6	2	10	3	8	9	5
58	3	1	4	10	7	2	6	9	8	5
59	4	1	5	7	6	8	3	10	9	2
60	3	4	5	6	1	9	8	10	7	2
61										
62	3	1	8	10	4	6	5	7	9	2
63	1	4	3	8	6	10	7	5	9	2
64	1	2	3	6	4	8	5	10	7	9
65	2	4	6	8	5	9	1	7	10	3
66	3	1	6	10	2	8	4	7	9	5
67	3	2	4	6	5	9	7	10	8	1
68	5	1	3	10	2	7	6	9	8	4
69	3	1	2	5	4	9	7	6	10	8
70	6	1	2	5	4	8	10	9	7	3
71										
72	1	1	3	5	1	7	2	1	2	1
73	1	2	6	10	4	8	3	5	9	7
74	4	2	3	6	7	10	5	9	8	1
75	1	2	6	4	7	9	8	5	10	3
76										
77	4	3	8	10	2	6	5	9	7	1

We Use Body Wires For:

Survey #	Officer Protection	Intelligence Gathering	Officer Testimony	Survey #	Officer Protection	Intelligence Gathering	Officer Testimony
1	y	y	y	41	y	y	y
2	y	y	y	42			
3				43	n	y	y
4	y	y	y	44	n	y	y
5	y	y	y	45			
6	y	y	y	46	y	y	y
7				47			
8				48	y	y	y
9	y	y	y	49			
10	y	y	y	50			
11	y	y	y	51	y	y	y
12		y		52	y	y	y
13	y	y	y	53	n	y	y
14	y	y	y	54			
15	y	y	y	55	y	y	y
16	y	y	y	56	y	y	n
17	y	n	y	57	y	y	y
18	y	y	n	58	y	y	y
19	y	y	y	59			
20	y	y	y	60	y	n	y
21	y	y	y	61			
22	y	y	y	62	y	y	y
23	y	y	n	63	y	y	y
24				64			
25				65	y	y	y
26	y	y	y	66	y	y	y
27	y	y	y	67	y	y	
28				68	y	y	y
29				69	y	y	y
30	y	y	y	70	y	n	n
31	y	y	y	71			
32	y	y	y	72	y	y	y
33				73	y		
34	y	y	y	74	y	y	y
35	y	y	y	75	y	y	y
36	y	y	y	76			
37	y	y	y	77	n	y	y
38	y	y	y				
39	y	y	y				
40							

What improvement would you like to see in your current equipment?

Survey #

#	Response
1	I'm very pleased with TTI's body Wire
2	Range & Quality of Recording
3	
4	
5	Noise Filtering
6	None
7	
8	
9	Clarity
10	Further, Stronger Transmissions
11	Reliability of signal to cover units
12	Size
13	First to obtain additional equipment. To get more range on our transmitter
14	Better Range and clarity
15	Smaller, greater range.
16	
17	Lower cost
18	Smaller, more audible
19	Greater Range and battery life
20	Would like to go digital with repeater system
21	Simpler Operation
22	We are satisfied
23	Overall I'm pleased with my radio and earpiece. I would like to upgrade to hands free, voice activated comm. Officer Safety issue - keep my hands free.
24	n/a
25	
26	Size (power source) heavier duty cords (to keep size to a minimum maybe shield w/kevlar for strength) to prevent internal wire breakage to a minimum
27	more durability
28	
29	
30	better clarity with signal
31	Consistent range without a repeater
32	Sturdier connection between antenna and plug/connector as well as mic and plug/connector
33	
34	
35	
36	Range of Transmitter
37	Overall transmitted voice quality and separation from background noise
38	size
39	size
40	
41	Purchased new wires within 2 months
42	1 watt in small size and 800 MHz body wire
43	smaller, more concealable body wires
44	audio clarity
45	
46	
47	

48	Encryption on all available transmitters.
49	
50	
51	To be not detectable by counter-measures (RF-detector/counter, etc) Also be digital.
52	Updated
53	Change to cellular transmission or synthesized systems
54	
55	More Units
56	
57	
58	I would like it to be smaller and to have a built in digital recorder
59	
60	n/a
61	
62	increased transmitter wattage for increased range
63	
64	
65	Durability
66	Longer Range, mike sensitivity, battery life
67	Increased mike sensitivity, more concealable repeater
68	Range and Durability
69	
70	Lighter in weight
71	
72	Make it smaller, easier to conceal, clarity
73	Frequencies on devices that can't be detected.
74	Updated concealment covers, better range, more power, smaller size.
75	Sound quality and range/concealment/we need video, video, video !!!
76	
77	Better Concealability