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Application of Computer-Controlled Spectrum Surveillance Systems to Crime Countermeasures

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***Abstract*—A computer-controlled spectrum surveillance system, and application of such a system to crime countermeasures, is described. The system covers the frequency range of 5 kHz to 12 GHz. All functions are controlled via mini-computer, with output directly compatible with batch processing computers.**

INTRODUCTION

THE NEED to utilize the electromagnetic spectrum as a crime countermeasures tool has been recognized for a number of years. All organizations involved in fighting crime use communications today in their operations. Such tools as high-speed data links, radar, and computers have also been integrated into the crime countermeasures field. It has become extremely important that those involved in combatting crime have complete control and management of the electromagnetic spectrum in which they intend their operations.

Heretofore, crude attempts have been made to provide limited-range frequency surveillance which could be utilized in the frequency-management task. However, such systems required manual operation, interpretation by highly trained operators, and, in general, a large quantity of equipment which was not easily transported and not at all compatible with high-speed data processing.

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In this discussion an attempt is made to describe equipment and systems which can be used in this function. They are, in general, commercially available and can be operated by variably untrained technical personnel.

Some examples are given of the applications these systems can be utilized for. No attempt will be made to get into the detail system requirements. However, the basic design tradeoffs and interface requirements are discussed.

SYSTEM DESCRIPTION

The spectrum surveillance system discussed in this technical paper differs from other swept-tuned receivers and spectrum analyzers in that it was designed from its inception to be a computer-controlled system. The system was conceived and designed to provide maximum flexibility, and to minimize software and interface requirements. It utilizes current generation mini-computers, with a 16-bit word format. The system not only controls the RF sections, but also allows computation and analysis of the data obtained.

In order to build a receiving system which is completely computer compatible, the old concepts of swept-tuned local oscillators, tuned RF stages, and fixed IF frequencies and bandwidths had to be revised. The computer-controlled spectrum surveillance system described here begins with a synthesized local oscillator which, in effect, is a number of local oscillators synthesized from a

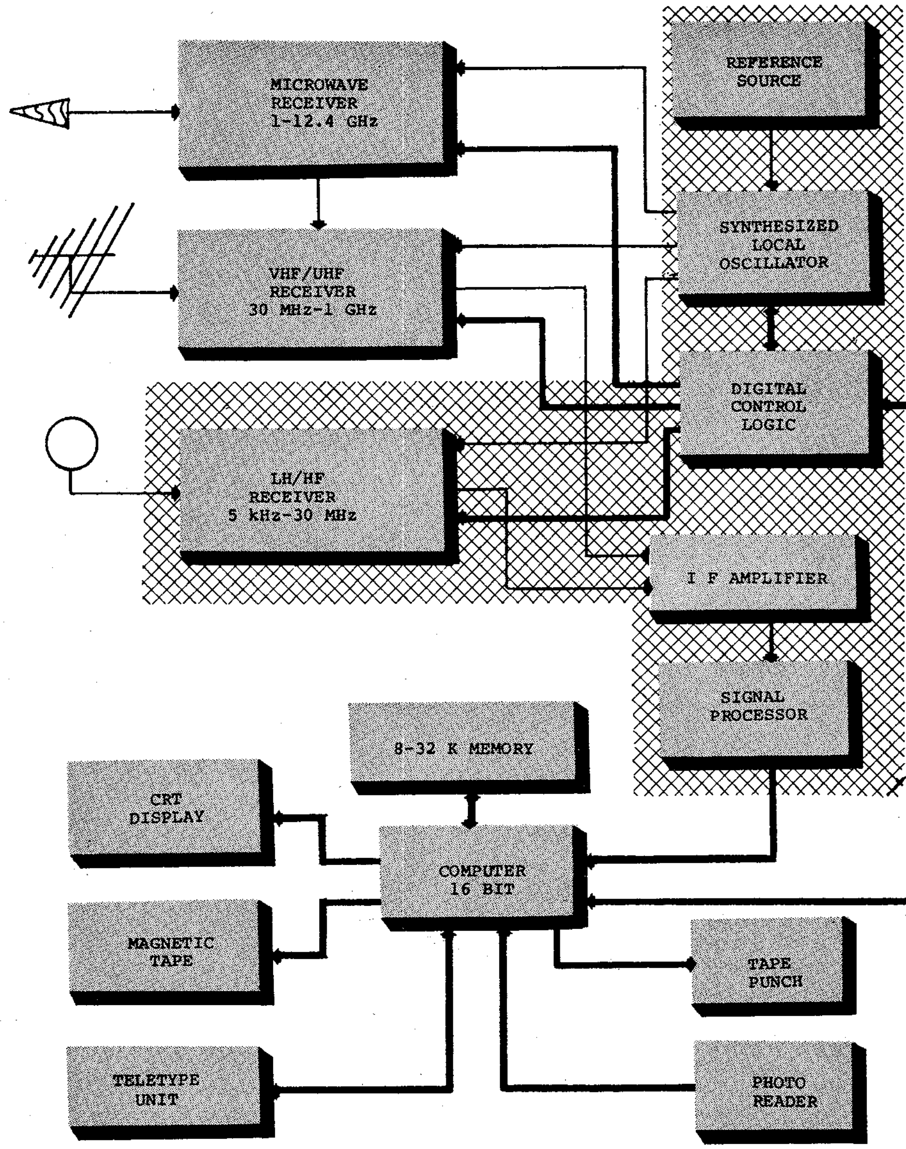

Fig. 1. Block diagram of computer-controlled spectrum surveillance system.

single reference source. The entire receiving system is referenced to this single system standard. This scheme provides for local oscillator stability many orders of magnitude greater than conventional swept-tuned units. It also allows the user to choose a system with frequency accuracies consistent with his capital equipment requirements and economic constraints.

The reference standard may be a simple crystal oscillator, or it may be as sophisticated as a cesium beam standard. The synthesized approach also allows convenient digital control of frequency, as well as convenient numerical display. The appropriate LOs are routed to the RF units. Fig. 1 shows a block diagram of a computer-controlled spectrum surveillance system.

The three RF preselection units covering the frequency range of 5 kHz to 12.4 GHz are shown in the upper left corner of the figure. The frequency ranges of the RF units are chosen to be consistent with 1) current-frequency allocation assignments, 2) available intercept antennas, and 3) antenna-cable transmission losses. The lowest unit is the LF/HF tuner, which covers the frequency range of 5 kHz to 30 MHz. The LF/HF unit is housed in the same package as the synthesizer digital-control logic and signal-processing components.

The second RF tuner is the VHF/UHF front end. It covers the frequency range of 30 MHz to 1 GHz. The VHF/UHF tuner may be either located adjacent to the signal-processing synthesizer package, or located remotely to minimize cable loss between receiving antennas or for convenience of system configuration.

The third RF tuner package covers the frequency range of 1 GHz to 12.4 GHz, and is specifically designed for remote operation to avoid the cable losses incurred in coaxial transmission at these frequencies. The micro-

TABLE I
RF CHARACTERISTICS

	LH/HF	VHF/UHF	Microwave
Frequency Range	5 kHz-30 MHz	30 MHz-1 GHz	1 GHz-12.4 GHz
Noise Figure	4 dB	10 dB	19 dB
Frequency Accuracy	1 x 10^7	1 x 10^7	1 x 10^7
Bandwidth	---------- 200 Hz to 20 MHz Continuous ----------		
Dynamic Range	70 dB	70 dB	70 dB
Sensitivity (CW)	- 147 dBm	- 141 dBm	- 132 dBm
Sensitivity (WB).	28 dBuV/MHz to -6 dBuV/MHz	0 dBuV/MHz	9 dBuV/MHz
IF Rejection	60 dB	60 dB	80 dB
Image Rejectioon	60 dB	60 dB	70 dB
Spurious Rejection	60 dB	60 dB	85 dB
IF Frequencies	60 MHz	300 MHz, 3 GHz	200-600 MHz

wave tuner utilizes multioctave yig preselectors. The output of the microwave tuner is an IF in the UHF band. The IF is fed into the tuner package which, in turn, acts as a swept IF unit. Table I is a summary of typical RF input characteristics.

This unique combination of fixed local oscillators and swept IFs provides for a system that is not only extremely accurate in frequency but also very economical. It eliminates the requirement for traveling-wave tube (TWT) amplifiers and backward-wave oscillators (BWO), which are inherently unreliable and extremely expensive.

The outputs of receivers are connected to a common IF section which provides necessary IF gain, blanking, and also a unique feature—continuously variable IF bandwidth. The output of the IF section is demodulated, and the signal processing circuitry modulation characteristics, such as AM, FM, and single sideband, are provided for signal analysis. The analog signal amplitude data are converted to digital data at the signal processor and routed to the computer for analysis. Since the computer generates the frequency information, all necessary information for signal processing and data storage are in the computer in the most convenient form.

The computer is of the mini-computer type, typically a Hewlett-Packard 2114C or a Digital Equipment Corporation PDP11. These computers are 16-bit word length, with memory capabilities of 4 K to 32 K, expandable by the customer according to mission demands. Typically, the control and operation of the system, with minor arithmetic operations, can be accomplished with an 8-K memory. A 16-K memory allows a number of analysis operations, convenient data storage on magnetic tape, and a number of subroutines. A 32-K memory provides for a fairly sophisticated system, with the ability to perform a number of analysis functions at the immediate site, to control a number of peripheral devices, and to program storage of various subroutines.

The system display is a CRT unit driven by the computer. A wide variety of data can be displayed, such as spectrum signatures, antenna patterns, time and amplitude plots, and channel usage displays. Data storage is on IBM compatible magnetic tape. Data from the magnetic tape may be taken to a batch processing center for analysis on a large-scale computer.

TABLE II
SYSTEM FEATURES

Frequency Resolution	plus or minus 100 Hz
Logic Type	TTL
Output Formats	BCD, Digital, Analog
Detection	AM, FM, AM/FM, SSB Peak Carrier Quasi Peak
System Dynamic Range	166 dB
Program Entry	Teletype, ASR-35 Paper Tape Magnetic Tape
Data Storage	Magnetic Tape X-Y Graphs Paper Tape Tabular - TTY
Data Display	CRT Digital, Frequency and Amplitude Tabular, TTY X-Y Graphs
Computer Word Size	16 Data Bits
Computer Memory	4 k to 32 k
Languages	FORTRAN, ALGOL, BASIC, Assembler

Human interface to the system is by the three blocks at the bottom of Fig. 1. Control, program entry, changes in program, status information, and tabular outputs are available, utilizing Teletypewriter console, photo reader for reading paper-tape programs and tape punch, which is used to make high-speed tape outputs of data and/or programs. Table II shows some of the system features.

Software requirements for the system are relatively simple since many of the functions and subroutines normally required in analog-instrumentation control are built into digital-control systems. Programs can be written in Basic, Fortran, and Assembler. Generally, a combination of these is used to provide maximum flexibility and to allow programming by relatively unskilled computer personnel.

With a set of the standard modular subroutines currently available for the system, a system operator can write, edit, and execute programs in the field with amazing ease. No sophisticated programmers and/or peripheral equipments are required to perform the functions described in this paper.

Applications

Thus far in this technical discussion, prime emphasis has been on systems concepts and the overall hardware requirements for a computer-controlled spectrum surveillance system. Although the specifications and hardware are impressive, applications for such systems are extremely interesting.

The idea of utilizing swept-frequency receiving systems in countermeasures is by no means novel or unique. However, utilization of such programmable systems by law enforcement agencies leads to an entirely new development of uses and applications.

The most significant use of a computer-controlled spectrum surveillance system occurs in areas associated with communications—the basic premise being that "a superior law enforcement system requires a superior communications system." It is a well-known fact that practically every law enforcement element, from the Federal Government to the smallest municipality, utilizes RF communications in its efforts to combat crime. For this basic reason—sheer quantities of communications links—it is necessary to provide an overall management of these communications systems.

Computer-controlled spectrum surveillance systems can be used to monitor channel utilizations and provide real-time feedback of the most usable communications channels. If certain channels are being overused, while others are being neglected, the frequency survellance system can provide operators and schedulers with up-to-date information on which channels will provide the best means of communication. Certainly one of the most important factors is that of traffic flow or the amount of messages being sent, but in addition to these types of data, the surveillance system can take into account propagation characteristics of the RF signal, transmitter locations, location and population of receivers in the area, sources of electromagnetic interference, and, in the more sophisticated cases of crime countermeasures, can detect frequency spectrum jamming and provide real-time data on frequency bands free of the jamming source.

A good example is that of a civil disturbance in which a number of law enforcement agencies are deployed in an urban area in an effort to maintain law and order. Each of these agencies would have a number of mobile communications systems, from manpacks to automobile land-mobile communication sets. Their frequency allocations would lie from 20 MHz to more than 3 GHz. The computer-controlled spectrum surveillance system could then scan this entire frequency range and catalogue the frequencies utilized. A subroutine could be generated to analyze possible incompatibility situations which might make certain areas or communications systems inoperable. Terrain data could be fed into the system to determine the best frequency band or channel for a particular area or sector.

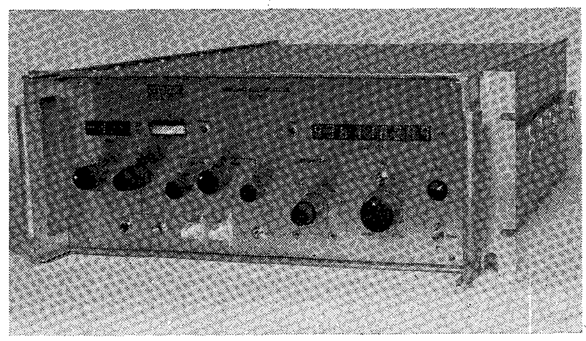

Fig. 2. BRT-35 receiver.

The computer-controlled spectrum surveillance system also can identify frequencies and locations of communications equipment not authorized for transmission. If the agitations are of a sufficient level of sophistication to jam communications by use of a broad-band or other type electromagnetic jamming source, the computer-controlled spectrum surveillance system can be programmed to recognize such a jamming source, to locate the direction of the source, and to identify the spectrum frequency being utilized.

A computer-controlled spectrum surveillance system configured in a mobile installation can also act as an emergency communications center, because of the ability of the system to receive over such a wide frequency spectrum. Since the current generation of systems has frequency accuracies equal to or better than the transmitters being utilized, with access to a wide range of detectors and discriminators, the system becomes an ideal wide-range communication system.

Thus far applications of the computer-controlled spectrum surveillance system in crime countermeasures during a maximum alert situation have been discussed. Although the system does adequately meet this need, it can be used in a number of tasks on a day-to-day basis, thus making it more economically feasible for broad coverage deployment.

An example of this flexibility would be the performance of propagation studies on current or future communication systems. A mobile configured system could be used to plot equal potential curves of field intensity at a number of channels and locations. The data could be utilized in the deployment of law enforcement personnel so as to avoid areas where communications are inaccessible or do not exist. Such data could show that it would be more appropriate to employ a VHF communication set in an urban area, while an HF set would be more effective in a suburban application due to its broader area of coverage.

From an economic standpoint, the data could be utilized by those procuring communications equipment

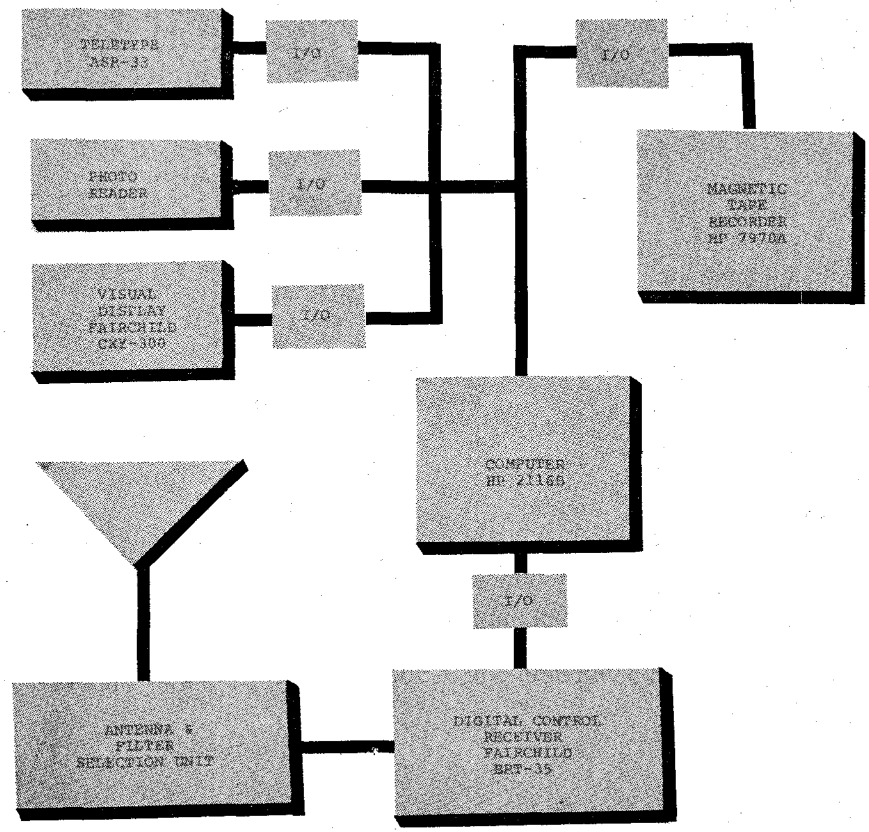

Fig. 3. Block diagram of mobile measurement system.

to show that certain sectors had sufficient transmitter power to permit the use of less expensive transceivers, or, that with a slight relocation of the transmitter, signal and noise ratios could be significantly improved.

Another application for the computer-controlled spectrum surveillance system is that of frequency assignments and channel utilization. Fairchild/Electro-Metrics Corp. is currently building a system for the Federal Communications Commission for the purpose of acquiring data on spectrum usage. The system consists of a broad-range variable bandwidth receiver, Model BRT-35 (Fig. 2), an on-board computer, magnetic tape, and video display systems.

A system block diagram is shown in Fig. 3. All of the system components are controlled by the system supervisor, an HP 2116 computer. The system automatically selects proper bandwidths, antennas, and display for the frequency range to be monitored. The system is capable of monitoring from 5 kHz to 1 GHz, and can be extended to 40 GHz. The receiver represents the state of the art in digital control wide-range receivers. Data are stored on magnetic tape and taken to a batch processing facility for data reduction and analysis. Two displays are provided, channel occupancy and channel spectrum. All control of the system is either by Teletype unit or a photo paper-tape reader. Stored programs on paper tape can be easily entered in the machine for rapid changeover of operations.

The entire system is mounted in a mobile camper-type capability. The heart of the entire system is the broad-band digital control receiver (BRT-35). This receiver was specifically designed with the capability of providing both a wide range of amplitude information and accurate frequency measurements. The receiver has capability of frequency stability greater than one part ten of the seventh. It has computer controllable bandwidths from 200 Hz to 20 MHz, and sensitivities as low as -147 dBm. All functions of the receiver are controllable by computer.

In the scan mode, the system will detect and record peak amplitude of the signal level in the channel as each channel is sampled during the scan. Since data-processing time is available, determination and recording of occupany data are accomplished.

Occupancy data can be corrected during each scan through a block of assigned channels. As each channel is sampled, the occupancy can be determined and a number corresponding to either an occupied or unoccupied channel can be added to the occupancy record for that particular channel. Occupancy, so stored for a given channel, can then be normalized using the scan number to obtain a record of percentage occupancy for that particular channel during the time scanning was in process. Occupancy information stored in the computer working storage is recorded on magnetic tape after the last scan of a particular frequency block is completed. Thus a given scan for a given five-minute period produces on magnetic tape a relatively long profile of amplitude versus channels and time information, followed by a relatively short profile containing the occupancy information on the given frequency block during the five-minute monitoring period.

Another mode of operation is a monitor mode. It would provide for monitoring of a single channel at a high-sample rate. This optional mode of operation can be implemented relatively easily with minor programming. This mode is very useful in determining precisely what percentage of time a channel is occupied. This information can be of special significance for specific channels, such as emergency channels and/or other channels which show unusual occupancy conditions.

A more sophisticated application of the computer-controlled spectrum surveillance system is that of locating transmitters being used for bugging and eavesdropping. The frequency range and the mobility of the system allow it to be moved easily into buildings where suspected transmitters may be located. Cable coupling devices can be used to check power and telephone lines for transmission of information to some remote transmitter.

Only a few of the more apparent applications of the system have been discussed. As hardware is being deployed in the field, more and more applications are being generated, utilizing the mini-computer concept and data output compatible with batch processing computers. Changing from one application to another only requires additional software, thus minimizing the obsolescence of the system and maximizing the user's capital investment dollars.

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A Discrete Point Approach to the Measurement of Radiated Power of Planar Apertures

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***Abstract*—It is shown that for a high-gain circular aperture with linearly polarized and rotationally symmetric excitation the total real radiated power can be expressed as a weighted sum of radiation intensities in N direction, where N is equal to the first integer greater than $2.14D_\lambda$. D_λ is the diameter of the aperture in wavelengths. In an N-point measurement scheme the N directions and the weights involved in the weighted sum of radiation intensities are completely independent of the parameters of the radiation system and can be obtained from the well-known and tabulated properties of the Legendre polynomials. The criterion that N be equal to the first integer greater than $2.14D_\lambda$ is independent of any specific distribution in the aperture so long as it is of the type parabolic-on-a-pedestal. Such aperture distributions satisfy most needs and cover typical behavior of actual dish antennas. Even though the result of the threoretical formulation is that the above mentioned criterion for N holds good only for high directivity apertures, computational results show that for D_λ as small as 5 the error involved when N satisfies this criterion is less than 0.02 percent, and for D_λ equal to 7 the error reduces to 0.005 percent. This not only indicates that the criterion that N be equal to the first integer greater than $2.14D_\lambda$ holds good even for small values of D_λ, but it also shows the rapid decrease of error with increase in D_λ.**

A knowledge of the total radiated power is required for the determination of gain and radiation efficiency of an aperture. The discrete point approach to the measurement of total radiated power eliminates the need for using the conventional method of graphical integration of radiation patterns for the determination of the total radiated power. The method of graphical integration has been known to give erroneous results for high-gain apertures. Measurement of radiation intensities in the fine sidelobe structure is another source of error in the conventional method. In the discrete point approach the directions in which the radiation intensity need be measured tend to cluster around the normal to the aperture. This means fewer measurements in the fine sidelobe structure.

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I. Introduction

The total power radiated by an aperture is the integral of radiation intensity over all directions. In this paper we have shown that for circular apertures with rotationally symmetric excitation this integral for the total real radiated power can be given a discrete-point representation. We further show that this discrete-point representation can be of any order, but when the number of points is equal to or greater than $\|2.14D_\lambda\|$ for a high-gain aperture, ($D_\lambda \gg 1$) the error involved in such a representation is completely and entirely negligible. D_λ is the diameter of the aperture in wavelengths and $\|2.14D_\lambda\|$ denotes the first integer greater than the number $2.14D_\lambda$. Computational results