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SHORT-RANGE RADIO COMMUNICATIONS SYSTEM FOR MILITARY OPERATIONS IN BUILT-UP AREAS

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March 1977

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Dispersive-surface-acoustic wave devices were employed in an experimental spread-spectrum communications system for the transmission of voice and tone signals via radio and via urban media. A short-range clandestine communications capability was demonstrated with this system competing with standard VHF radio transceivers.

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SHORT-RANGE RADIO COMMUNICATIONS SYSTEM FOR MILITARY OPERATIONS IN BUILT-UP AREAS

INTRODUCTION

The need to maintain radio silence to the enemy and to concurrently communicate with a friendly element are conflicting requirements that arise in many operations. During military encounters, these two conflicting capabilities are critical to small units carrying out military operations in built-up areas (MOBA) [1], [2], [3]. The wires and cables presently used to maintain communications between defensive units restrict the mobility of troops and equipment and, at the same time, enhance the possibility of damage to the wires and cables themselves by enemy fire and by saboteurs.

Recent important advances in dispersive surface-acoustic-wave (DSAW) technology led to the idea that DSAW devices might be useful in a communication system for MOBA. Accordingly, the subsequently described radio transmission and reception experiments were conducted to determine whether these conflicting requirements--for radio communications and concurrent radio silence--can be resolved by using spread spectrum techniques for short-range communications. The resulting clandestine radio communications technique employs the existing natural noise and/or man-made radio interference (RFI) to reduce the chances that radio emissions will be detected and messages intercepted by someone other than the desired communications partner.

Consequently, such a clandestine radio communications arrangement requires two operations: (1) the camouflage of signal emissions to prevent radio surveillance in general and (2) the unveiling of the emitted signal to the desired clandestine communications partner. The concept of "chirp pulses" as presently used in radar technology was adapted for use in the described exploratory-type experimental system for clandestine radio communications. This communications system utilized dispersive surface-acoustic-wave (DSAW) devices to expand the emitted signal and to subsequently compress the received signal. The application of DSAW devices to communications differs from the application of radar devices to surveillance. In the latter case, where target resolution is the main objective, a *maximum* of power is necessary to illuminate the target, whereas in the case of clandestine communications, an attempt is made to transmit information with a *minimum* of power [4], [5].

---

[1] Herbert W. Head, "Small unit communications in built up areas," presented at the U. S. Army Command and General Staff College, Department of Strategy, April 1975.

[2] J. Meehan, "Urban combat: The Soviet view," *Military Review*, September 1974.

[3] *Proc. of Symposium on Combat in Urban Areas*, U. S. Army Munitions Command, Picatinny Arsenal, Dover, N. J., March 14-15, 1973.

[4] DeLamar T. Bell, Jr., Jerry D. Holmes, and Richard V. Ridings, "Application of acoustic surface-wave technology to spread spectrum techniques," *IEEE Trans. Microwave Theory & Techniques*, vol. MTT-21, no. 4, April 1973.

[5] *Proc. IEEE, Special Issue on Surface Acoustic Wave Devices and Applications*, vol. 64, no. 5, pp. 577-832, May 1976.

A. PRINCIPLE OF OPERATION OF CLANDESTINE SYSTEM

A.1. Signal Generation and Emission

Basically in these investigations, a specific form of frequency dispersion was used to generate the clandestine signal. A 70 MHz carrier was 100% amplitude modulated with an 0.1-microsecond long pulse; the pulse repetition rate was in the 10 to 100 kHz range. The envelope of the frequency spectrum of such a pulse-modulated carrier ideally conforms to a $\frac{\sin x}{x}$ function. The clandestine signal is then obtained by a specific type of dispersion and a corresponding expansion of the pulse length. However, the frequency bandwidth of the original pulse is maintained. Dispersion and expansion were achieved by means of a dispersive surface-acoustic-wave (DSAW) device which had been designed specifically for this system. The overall dispersion of this DSAW device is quantified by a delay of 10-microseconds within a 10 MHz bandwidth (between 65 and 75 MHz). Although dispersion implies a chirp-like variation of the phase relations between the components of the pulse spectrum as functions of frequency, dispersion preserves the intrinsic coherency between the spectrum components while it expands the carrier-centered energy over the whole bandwidth. The resulting clandestine signal spectrum, therefore, is intrinsically coherent, although the overall wave shape of the clandestine signal resembles that of wide-band noise. It is this wide-band noise-like clandestine signal that conveys the signature of the transmitter's dispersive surface-acoustic-wave device.

Furthermore, when the level of the noise-like clandestine signal is adjusted to be equal-to or less-than that of the natural and man-made radio noise and interference, it is almost impossible to sense emissions of the clandestine signal by conventional radio receivers. As described in Sec. A.4, the clandestine signal transmissions become detectable only upon reversal of expansion, i.e., by compression of the clandestine signal pulses.

A.2. Theoretical Model of RF Pulse Dispersion

The dispersive process described in Sec. A.1. becomes mathematically tractable by approximating the rectangular pulses and their $\frac{\sin x}{x}$ spectra by Gaussian pulses and their Gaussian spectra. The Gaussian pulse input of the DSAW device can be formulated as:

$$g(t)\ [\exp(-a^2t^2)]\cdot\cos 2\pi f_0 t \qquad (1)$$

where:

t: time in seconds,

f_0: pulse carrier frequency in hertz,

a: pulse decrement in sec^{-1}.

The inverse, 1/a, of the pulse decrement represents the pulse length, i.e., the length of time during which the pulse decays from its maximal unit amplitude to $\frac{1}{e} = \frac{1}{2.7}$ (~10 dB). The corresponding bandwidth in the frequency domain follows then with a/π (that is, the frequency deviation at which the spectral amplitude is approximately 10 dB below the peak amplitude). This input pulse becomes dispersed by the DSAW device, which is characterized by a dispersion characteristic, i.e., the delay time τ versus frequency ν dependence:

$$\tau = t_0 + T_d^2 (\nu - f_0) \, , \tag{2}$$

where

t_0: delay of the carrier frequency f_0,

T_d^2: delay time per unit frequency, i.e., the slope of the dispersion characteristic.

The resultant dispersed output pulse from the DSAW device becomes:

$$g_d(t) = \frac{1}{\sqrt[4]{1 + \frac{4}{\pi^2} a^4 T_d^4}} \cdot \exp - \frac{a^2 (t - t_0)^2}{1 + \frac{4}{\pi^2} a^4 T_d^4}$$

$$\cdot \cos 2\pi \left\{ f_0^2 T_d^2 - \frac{1}{4\pi^2} \arctan \frac{2}{\pi} a^2 T_d^2 + \right. \tag{3}$$

$$\left. + f_0(t - t_0) + \frac{\frac{2}{\pi} a^2 T_d^2}{1 + \frac{4}{\pi^2} a^4 T_d^4} \cdot a^2 (t - t_0)^2 \right\} .$$

Since in practice $\frac{2}{\pi} a^2 T_d^2 >> 1$, the above equation can be approximated by:

$$g_d(t) \approx \frac{1}{\sqrt{\frac{2}{\pi}} \, a \, T_d} \cdot \exp - \left(\frac{a}{\frac{2}{\pi} a^2 T_d^2} \right)^2 \cdot (t - t_0)^2$$

$$\cdot \cos 2\pi \left\{ f_0 T_d^2 - \frac{1}{4\pi^2} \arctan \frac{2}{\pi} a^2 T_d^2 + f_0 (t - t_0) + \frac{(t - t_0)^2}{\frac{2}{\pi} \cdot T_d^2} \right\} . \tag{4}$$

A comparison of Eqs. (1) and (4) shows that the decrement a of the original pulse changes to the decrement $\frac{a}{\frac{2}{\pi} a^2 T_d^2}$ of the dispersed output pulse.

Consequently, dispersion of the original input pulse expands the pulse length by the factor $\frac{2}{\pi} a^2 T_d^2$ which would appear to reduce the impulse bandwidth. Actually, however, this bandwidth is determined by the argument in the cosine of Eq. (4). Furthermore, the amplitude of the original input pulse is reduced by the factor $\frac{1}{\sqrt{\frac{2}{\pi}} a \cdot T_d}$. However, dispersion affects not only the pulse amplitude function, but also the pulse carrier frequency function, which is described by the argument of the cosine term in Eq. (4). The first two terms in this argument express the constant phase shift associated with the dispersion; the third and fourth terms of the argument represent the time-dependent phase, which can be written in the form:

$$x = 2\pi(t - t_0) \cdot \left[f_0 + \frac{(t - t_0)}{\frac{2}{\pi} T_d^2} \right] . \quad (5)$$

This form (Eq. (5)) reveals that the fourth term shifts the original carrier frequency f_0 by

$$\Delta F = \frac{t - t_0}{\frac{2}{\pi} \cdot T_d^2} . \quad (6)$$

Hence, this frequency shift ΔF, which increases linearly with time t, is inversely proportional to T_d^2, the slope of the dispersion characteristic in Eq. (2). Such frequency shifts are known as "chirps."

A quantitative insight into the relations between the expanded pulse length and the frequency shift ΔF is obtained by choosing representative numerical values for a and f_0 of the pulse input, and for t_0 and T_d^2 of the dispersion characteristic of the DSAW device. For example, the introduction of

$$a = \frac{1}{0.1\ \mu sec} = 10^7\ sec^{-1}; \qquad f_0 = 100\ MHz = 10^8\ sec^{-1};$$

$$t_0 = 10\ \mu sec = 10^{-5}\ sec; \qquad T_d^2 = \frac{10\ \mu sec}{10\ MHz} = 10^{-12}\ sec^2$$

into Eqs. (1) and (4) yields:

$$g(t) = \exp(-10^{14}\ t^2 \cdot \cos 2\pi\ 10^8 t) \qquad (7)$$

$$g_d(t) \approx 0.125 \times \exp(-2.5 \times 10^{10} \times (t - t_0))^2 \cdot$$

$$\cdot \cos 2\pi \left\{ 10^4 - 0.025 \arctan \frac{2}{\pi} \times 10^2 + \right.$$

$$\left. + (t = t_0) \cdot \left[10^8 + \frac{\pi}{2} \cdot 10^{12}\ (t - t_0) \right] \right\}. \qquad (8)$$

The decrement of the dispersed output pulse, Eq. (8), is

$$a_d = \sqrt{2.5 \times 10^{10}}\ \sec^{-1} = 1.58 \times 10^5\ \sec^{-1}\ ; \qquad (9)$$

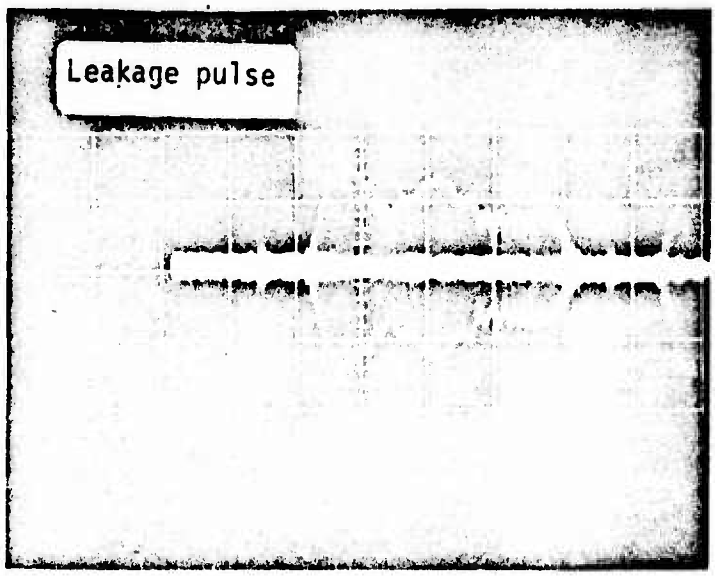
and the frequency shift of the carrier is

$$\Delta F = \frac{\pi}{2} \cdot 10^{12} \cdot (t - t_0)\ . \qquad (10)$$

Consequently, the dispersion ($t_0 = 10$ μsec and $T_d^2 = 10^{-12}$ $\sec^2$) increases the pulse length from $\tau = \frac{1}{a} = 0.1$ μsec to $\tau_d = \frac{1}{a_d} = 6.3$ μsec. In the corresponding time interval, $t_0 - \tau_d \leq t \leq t_0 + \tau_d$ (i.e., between 3.7 μsec and 16.3 μsec, counted from the time of occurrence of the peak of the input pulse), ΔF changes from -10 MHz to +10 MHz. The carrier frequency of the dispersed pulse, therefore, shifts from 90 MHz to 110 MHz. Hence dispersion does not reduce the frequency bandwidth required to transmit the energy in the original pulse of length $\tau = 0.1$ microseconds. It follows that when the instantaneous frequency passes through 90 and 110 MHz, the amplitudes of the leading edge and of the trailing edge of the dispersed Gaussian output pulse are equal to $\frac{1}{e} = \frac{1}{2.7}$ (approximately -10 dB) of the peak.

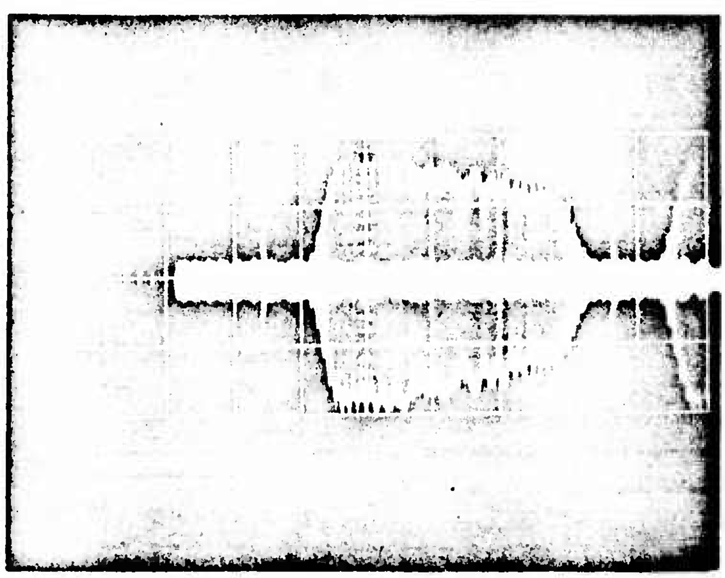
A.3. Electrical-Leakage-Pulse Interference Effects

Pulse dispersion devices, such as surface-acoustic-wave delay lines, are not ideal electroacoustic transducers. In addition to being lossy, they are also leaky electrically, that is, part of the applied electrical energy leaks directly from the emitter to the receiver transducer electrode (see Figs. 1 and 2). The electrical leakage of the input pulse through the transducer electrode capacitance to the output of the DSAW device leads to the superposition of the electrical leakage pulse on the dispersed output pulse. The peaks of the electrical leakage pulse and of the succeeding dispersed pulse output from the device are clearly separated in time by the delay t_0. Yet the trailing edge of the leakage pulse and the leading edge of the dispersed pulse may interfere. In theory, the linear superposition of the electrical



0.2 V/cm XMTR signal through antenna 2.0 μs/cm

Fig. 1. Close-up of scope display of transmitter's output: emitted clandestine signal wave shape at transmitter's antenna input.



0.2 V/cm XMTR signal, no antenna 2.0 μs/cm

Fig. 2. Close-up of scope display of transmitter's output: clandestine signal wave shape at the output of the transmitter operating into a 50-ohm dummy load.

leakage pulse on the dispersed pulse should constitute a second order effect. In practice, however, spurious nonlinearities in the transmitter and/or nonlinear detection by sensitive radio receivers result in the mixing of the leakage and dispersed pulse frequencies. Consequently, with insufficient suppression of the electrical leakage which passes through the DSAW device, the emission of the dispersed pulses (the clandestine signals) can be deduced from frequency mixing products. These products can be detected by ordinary radio sets. The detrimental role of the electrical leakage pulse became evident when pulse rate modulation was introduced into the experimental system to achieve a voice transmission capability. The functioning of the clandestine radio system, therefore, depends to a large extent on the degree of suppression of this leakage pulse.

A.4. Clandestine Signal Reception and Display

Reception of the clandestine signal amounts to restoration of the original pulse spectrum by means of "conjugate dispersion," i.e., compression of the received signal spectrum which was buried in the noise. For this purpose at the receiver, the noise and the clandestine signal--buried in the noise--are passed through a second dispersive surface-acoustic-wave device. The dispersion characteristic of the DSAW device in the receiver must be exactly conjugate to that of the DSAW device in the transmitter. Consequently, the DSAW device in the receiver disperses the incoherent noise further, whereas the clandestine signal spectrum is compressed into the $\frac{\sin x}{x}$ type spectrum of the original pulse. The peak levels of the restored pulse then exceed the noise levels such that a bias detector can be used to detect the signal pulse above the dispersed noise (see Fig. 3).

In this connection, it is necessary to point out that equally-dispersive, instead of conjugate dispersive, surface-acoustic-wave devices were used in the initial experiments, Versions 1 through 4. The conjugate dispersion and the resultant compression of the received chirp-pulses by the receiver were approximated by inverting the upper and the lower sidebands of the clandestine signal relative to the 70 MHz center frequency. For this purpose, the noise-covered clandestine signal was mixed with a 140 MHz CW signal from a local oscillator. The resultant mixing products were then fed into the receiver's DSAW device. (In later versions of the system, Versions 2 through 4, the same 140 MHz oscillator and mixer were used at the transmitter for inversion of the signal sidebands. In still later versions, Versions 5 and 6, the pair of equally dispersive surface-acoustic-wave (DSAW) devices was replaced by a pair of conjugate DSAW devices that operated in the same 65-75 MHz range.)

B. SYNOPSIS OF EXPERIMENTS

Clandestine signal-transmission and -reception experiments in the 65 to 75 MHz band were conducted between Bldg. S-29 and Bldg. 6 in the Evans Area, a distance of ~600 feet. Commercial TV antennas on these buildings (see Figs. 4 and 5) were used during most of these experiments, but in one case whip antennas (AS-1729/VRC) were used on vehicles that were parked next to the buildings. The original transmitters and receivers were improvised from standard laboratory test equipments. Several versions of transmitter and receiver configurations were set up. The final, i.e., sixth, version of the receiver was constructed as a portable unit from commercially available amplifier models (Avantek UDP-21) and from electronic circuits which had been designed and

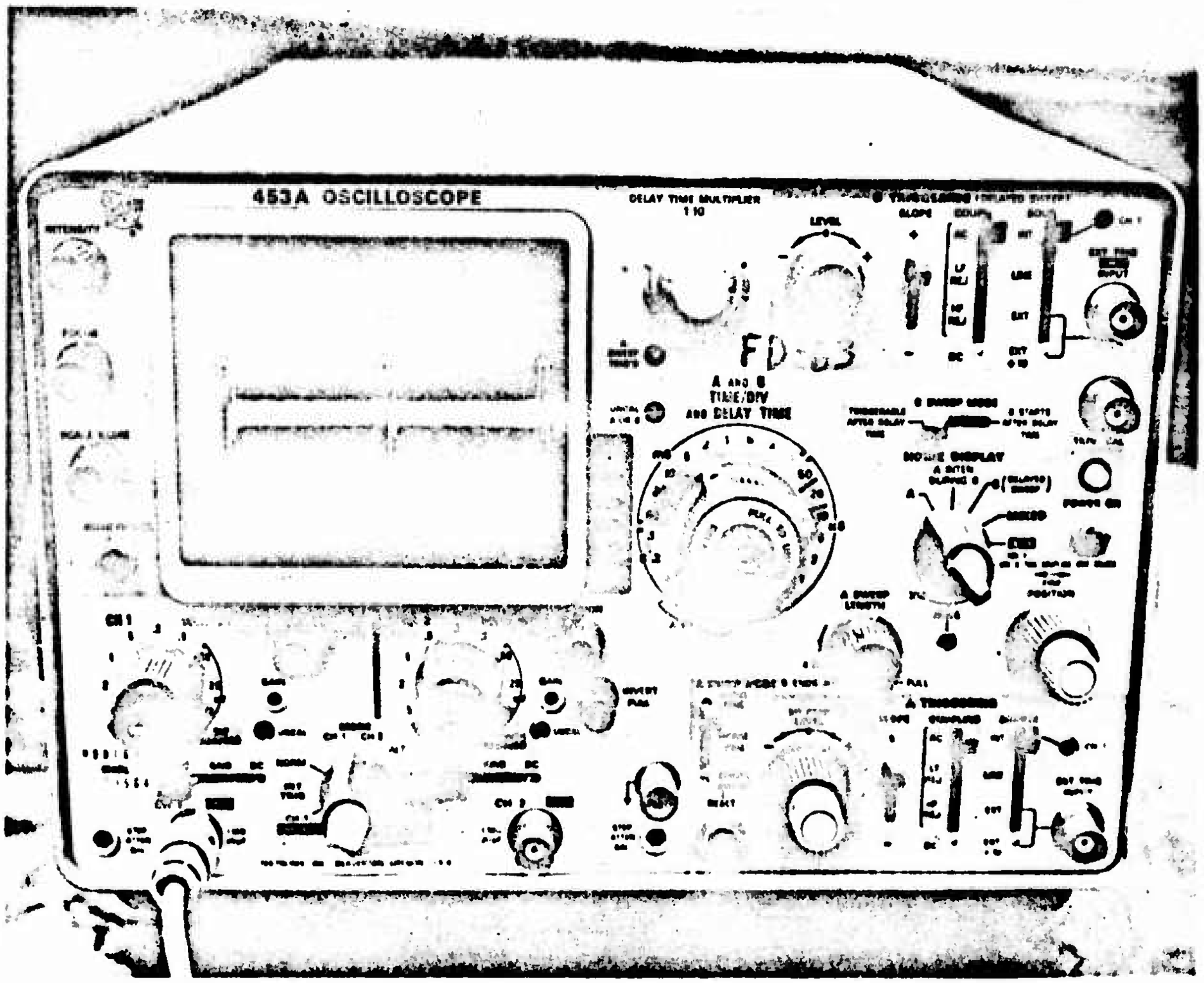


Fig. 3. Scope display of received and compressed signal pulse above RFI and noise at output of receiver LF amplifier stage.

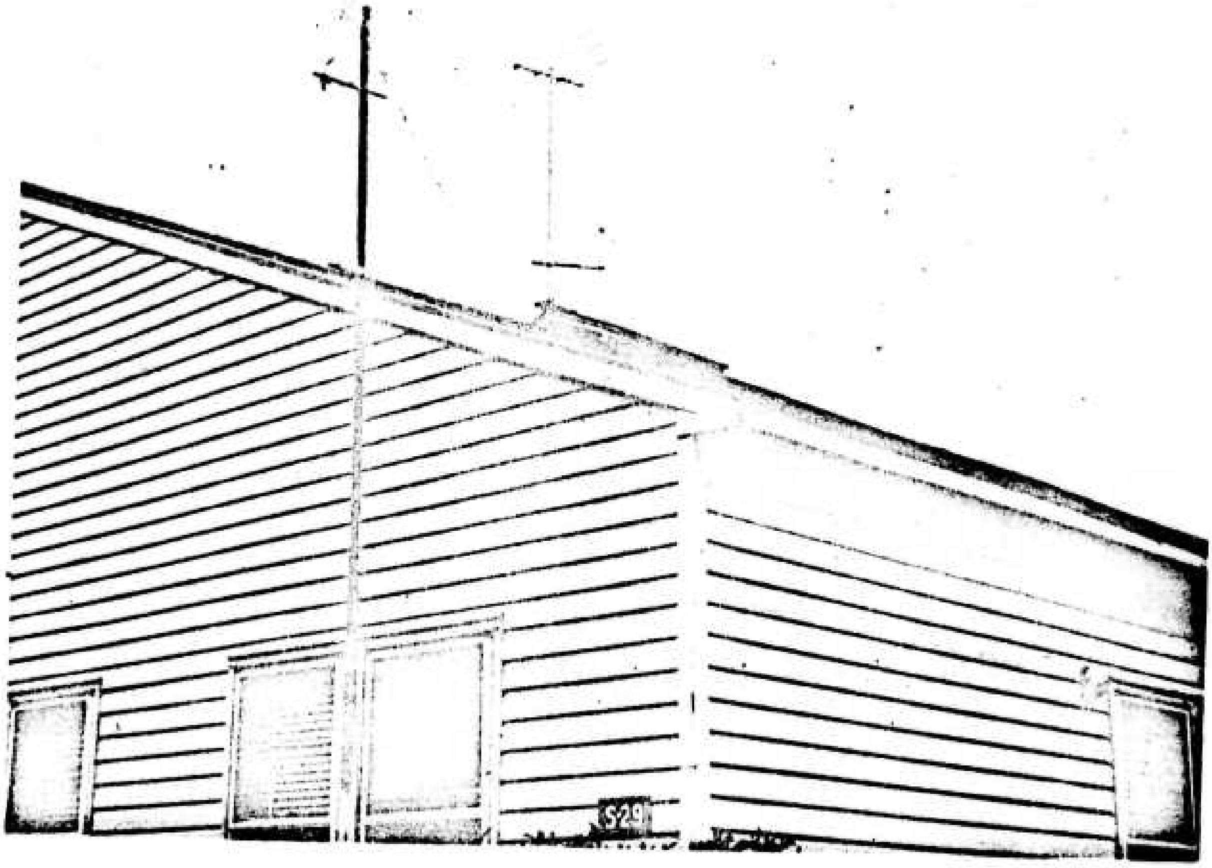


Fig. 4. TV antenna on Bldg. S-29, Evans Area.

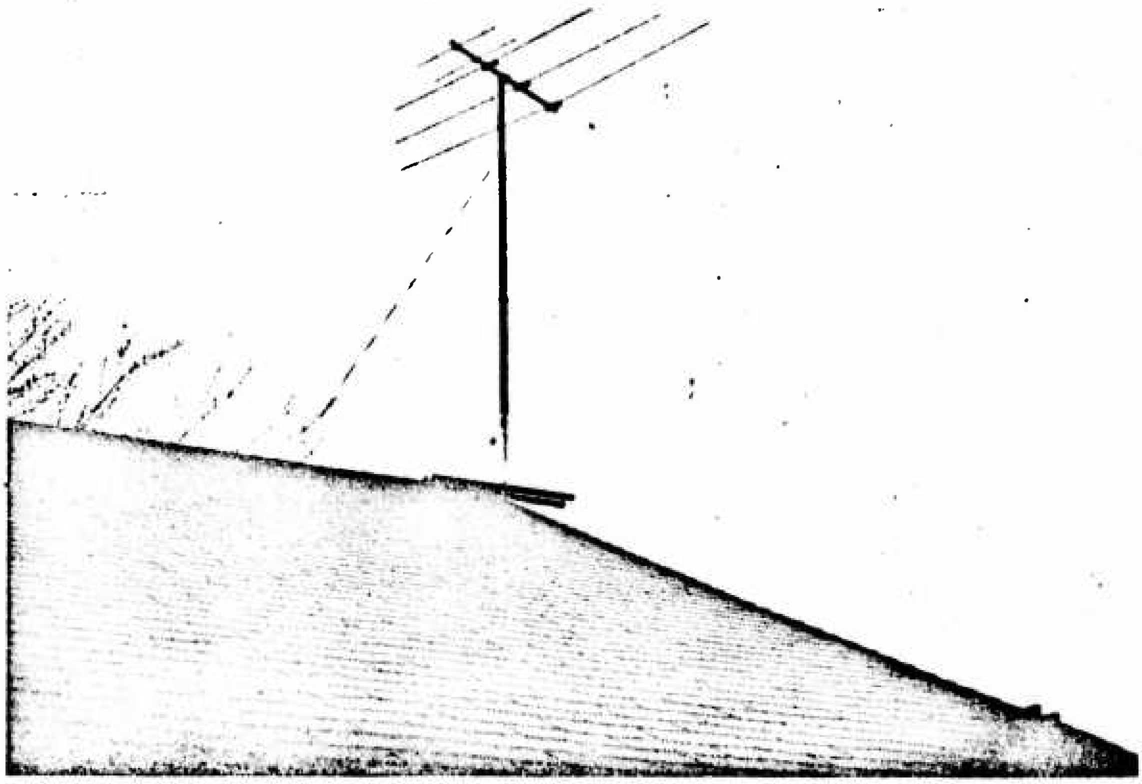


Fig. 5. TV antenna on Bldg. 6, Evans Area.

fabricated in-house. All versions of the transmitter and receiver used dispersive surface-acoustic-wave (DSAW) devices, which had also been fabricated in-house.

In System Versions 1 through 4, equally dispersive surface-acoustic-wave devices (i.e., having the same slope $\Delta T/\Delta f$) were used in both the transmitter and receiver. These DSAW devices had a dispersion of $\sim$0.6 μs per megahertz within the 65 to 75 MHz band and a pulse compression gain of about 17:1. Their CW loss at around 70 MHz was of the order of 40 dB, primarily because temperature stable substrates were used. Approximate conjugate spectra of the pulse signals were formed in the initial four versions of the system with a 140 MHz heterodyne circuit that inverted the upper and the lower sideband of the pulse signals relative to the 70 MHz center frequency. In Version 1, the 140 MHz heterodyne circuit was installed in the receiver, while in Versions 3 and 4, the circuit was installed in the transmitter. In the fifth and sixth versions, the 140 MHz heterodyne circuit was eliminated because the equally-dispersive acoustic-surface-wave devices were replaced by similar, but conjugate DSAW devices. (These conjugate DSAW devices, which had been designed and fabricated in-house,became available for operation in the system on 19 Dec. 1975.) The fifth version of the system,which also employed conjugate DSAW devices, was improvised from amplifiers operated from the ac power line. In the sixth version, part of the transmitter circuit was improved by the use of special laboratory-constructed battery-operated circuits (see Figs. 6 and 7); the receiver was made completely battery-operated and portable (see Figs. 8 and 9). The first version of the experimental system was able to transmit and receive only ON-OFF keyed signals. Subsequent versions were used to transmit ON-OFF keyed audio tones as well as music and voice.

Experiments were conducted with different types of modulation. Pulse amplitude (PAM) and pulse rate (PRM) were used for the transmission of voice and music. The dominant mode of operation for transmitting voice was rate modulation of the 85- to 100-nanosecond long pulses, which in turn modulated a 70 MHz CW carrier frequency. The rate of these pulses was in the low frequency (LF) range, 30 to 70 kHz. The RF pulse spikes that were created at that rate were expanded from 85 to 100 nanoseconds to about 6.5 microseconds by the DSAW device of the transmitter. This expansion of the pulse length (from $\sim$100 nanoseconds to $\sim$5 microseconds) was accompanied by a chirp-like variation of the pulse carrier frequency within the spectral width of the original $\sim$100-nanosecond pulse. The expanded RF pulse signal was emitted and received by TV antennas. The clandestine features of the signal emissions followed from the intrinsic wide-band noise-like character of the emitted chirp-pulses and from the extremely low power levels (microwatts) fed into the transmitter antenna. The peaks of the chirp-pulse signals fed into the transmitter TV antenna were only 3 to 6 dB above the noise and RFI picked up by the transmitter antenna. The existing natural- and man-made noise and RFI included, foremost, RFI from TV Channel 4. Similarly, noise and RFI (TV Channel 4) were picked up by the TV antenna at the receiver. Consequently, at these low signal power levels, the emitted clandestine signal could not be detected within the existing RFI with a standard PRC-25 Set, even when this set, was hooked up to the TV antenna of the receiver. When the PRC-25 Set was used with its regular whip antenna (3' high), the clandestine signal emissions could be picked up only in very close proximity to the transmitter, i.e.,within 6 m of the feedline that connected the TV antenna on Bldg. S-29 with the clandestine transmitter inside (see Fig. 10). Consequently, an enemy unit equipped with regular tactical FM radios tuned to frequencies in the 65 to 75 MHz band would not

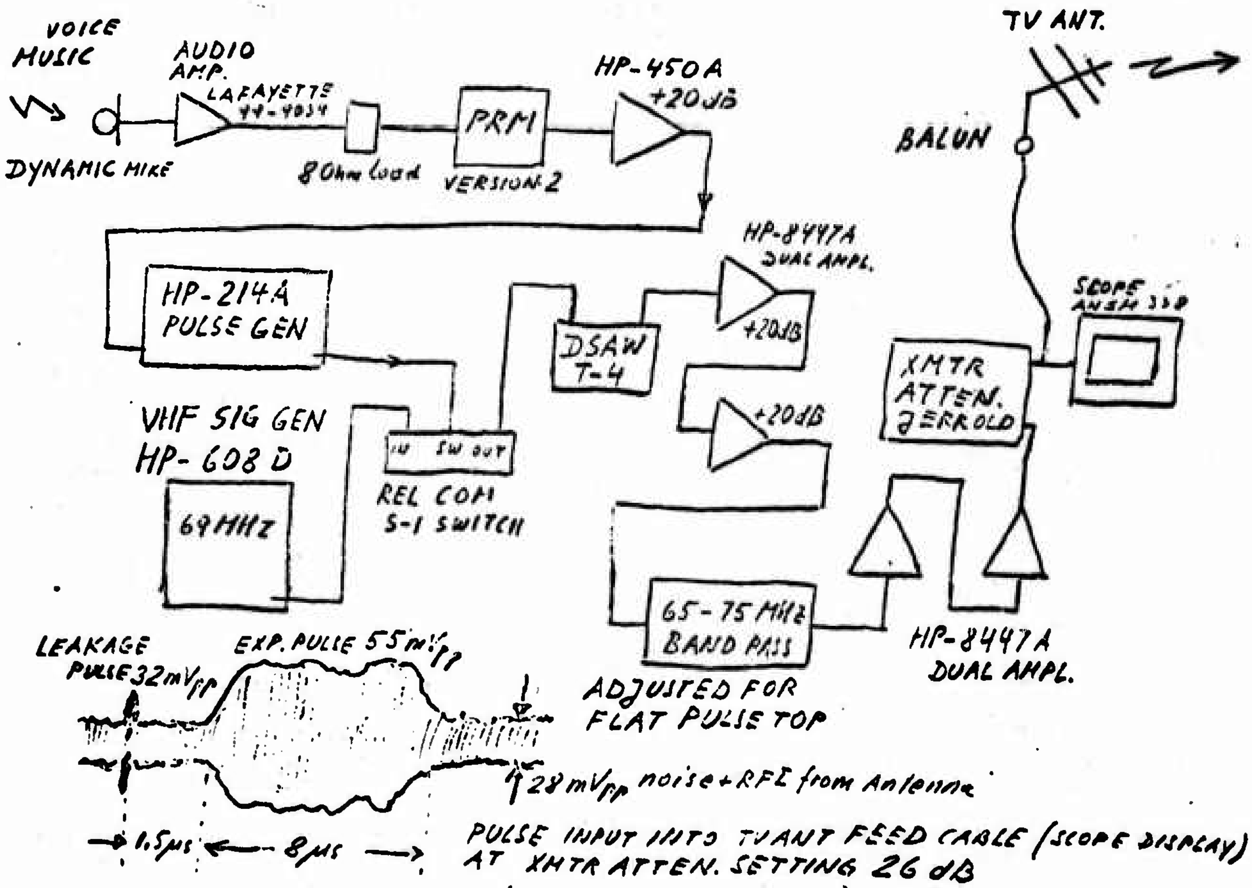


Fig. 6. Clandestine transmitter (Version 6, simplified) without blanking circuit for suppression of electrical leakage pulse; Block diagram (Bldg. S-29, Evans Area).

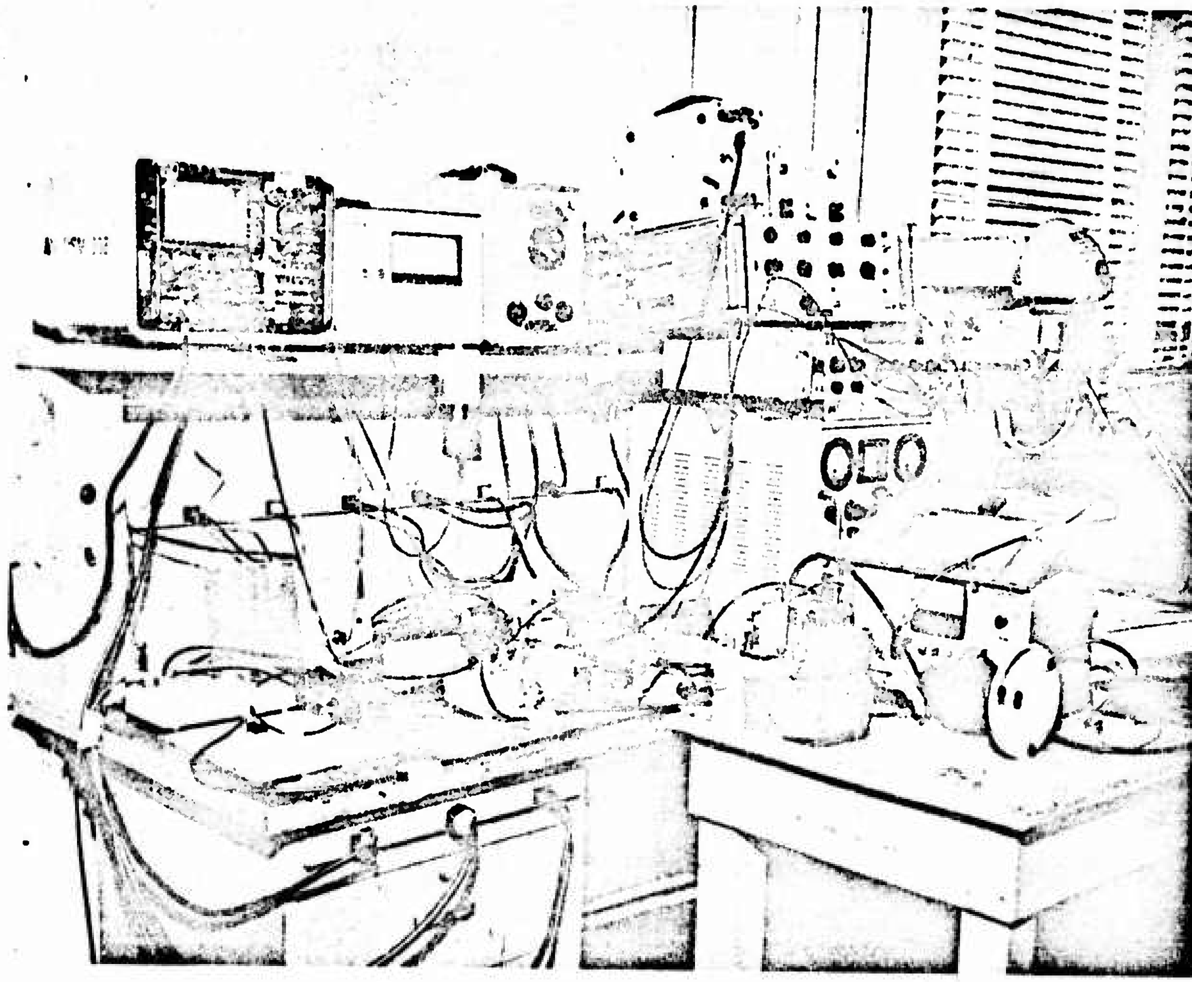


Fig. 7. Clandestine transmitter (Version 6, simplified) without blanking circuit for electrical leakage pulse suppression (Bldg. S-29, Evans Area).

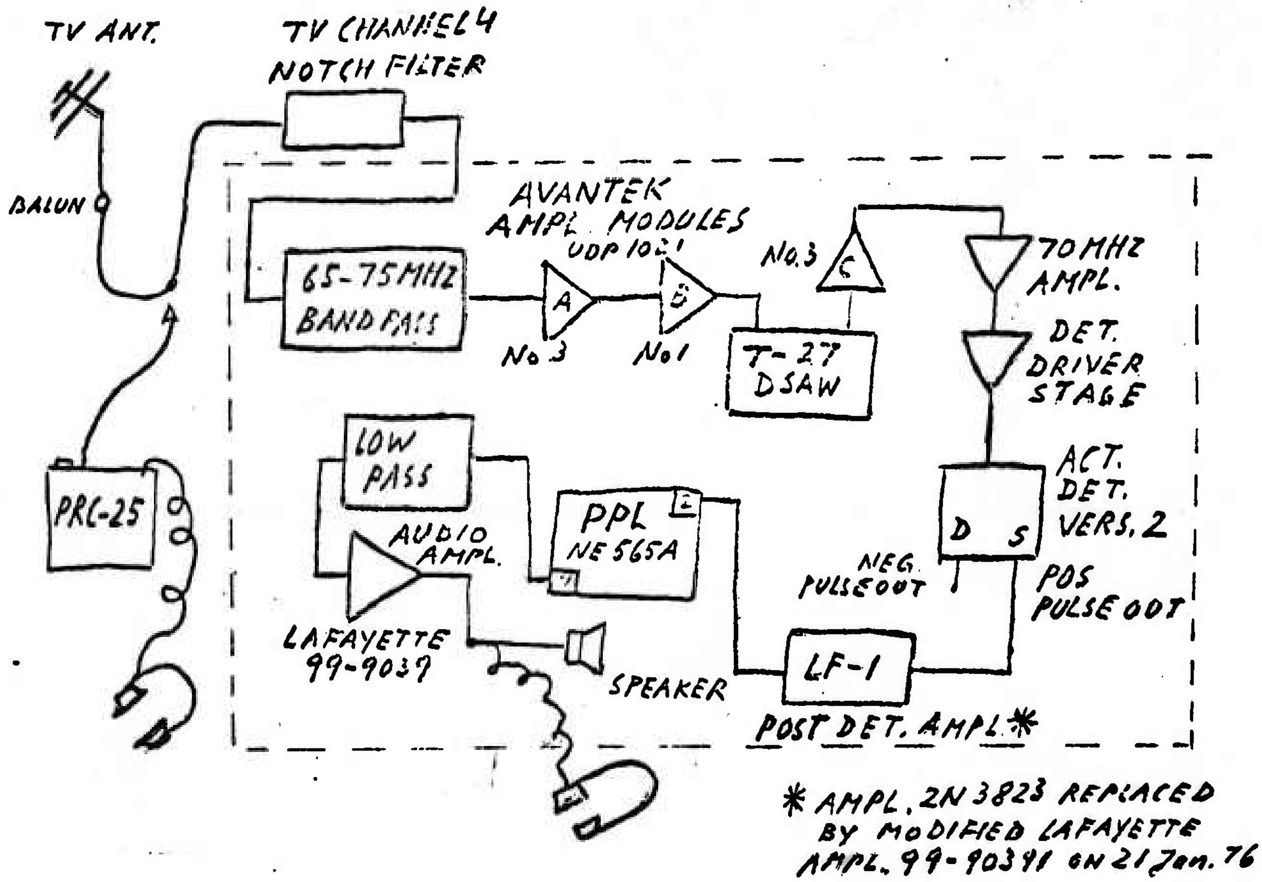


Fig. 8. Clandestine receiver (Version 6) battery-operated and portable; Block diagram, (Bldg. S-6, Evans Area).

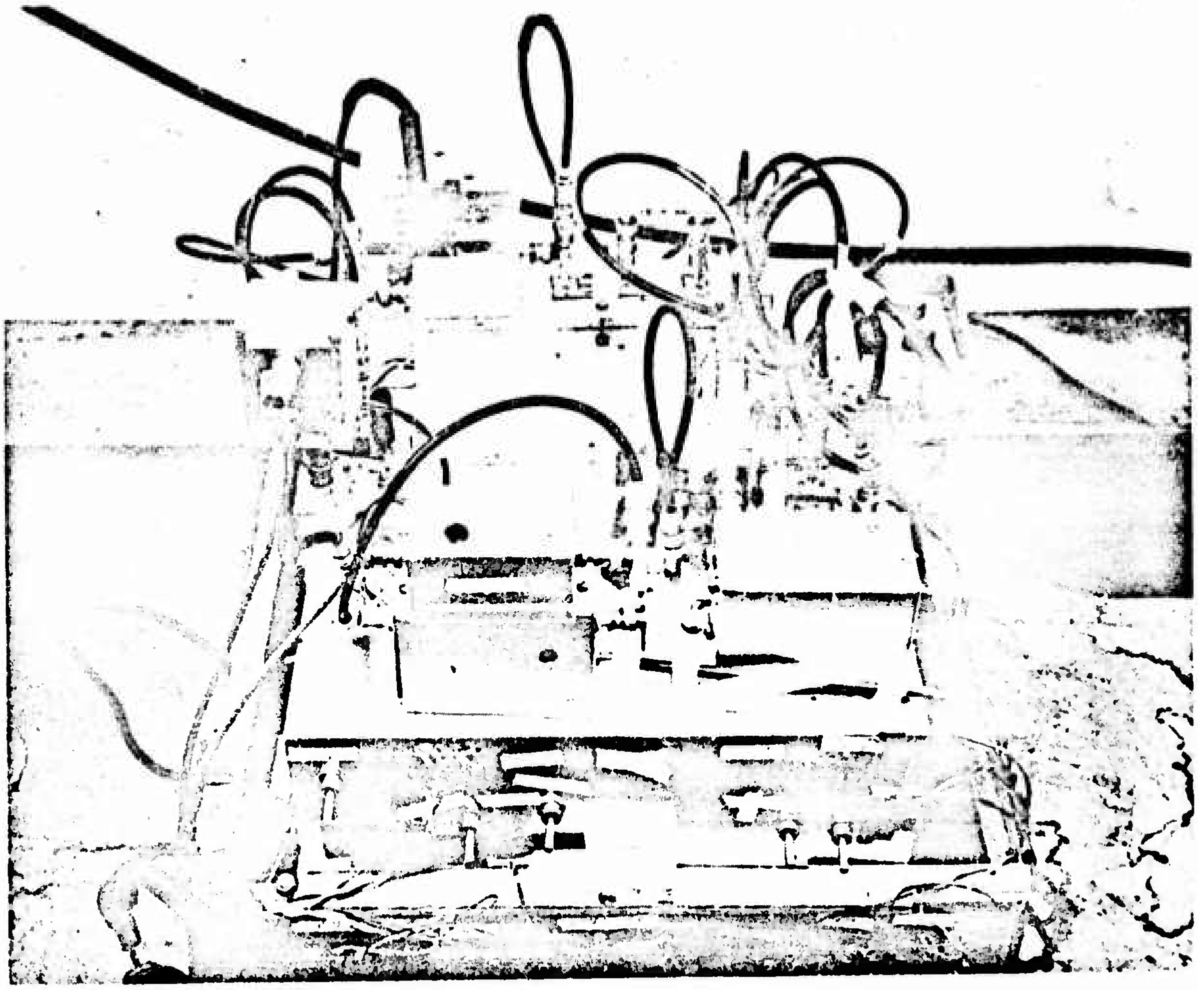


Fig. 9. Clandestine receiver (Version 6), close-up view (Bldg. S-6), (Evans Area).

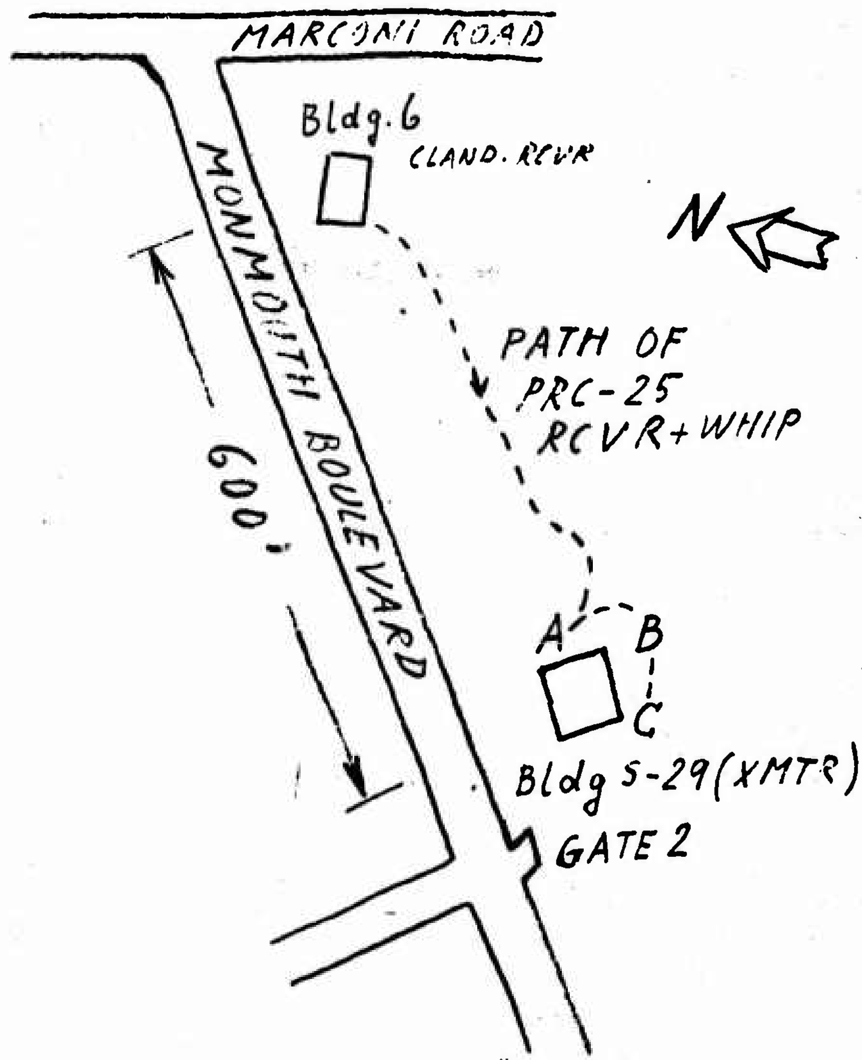
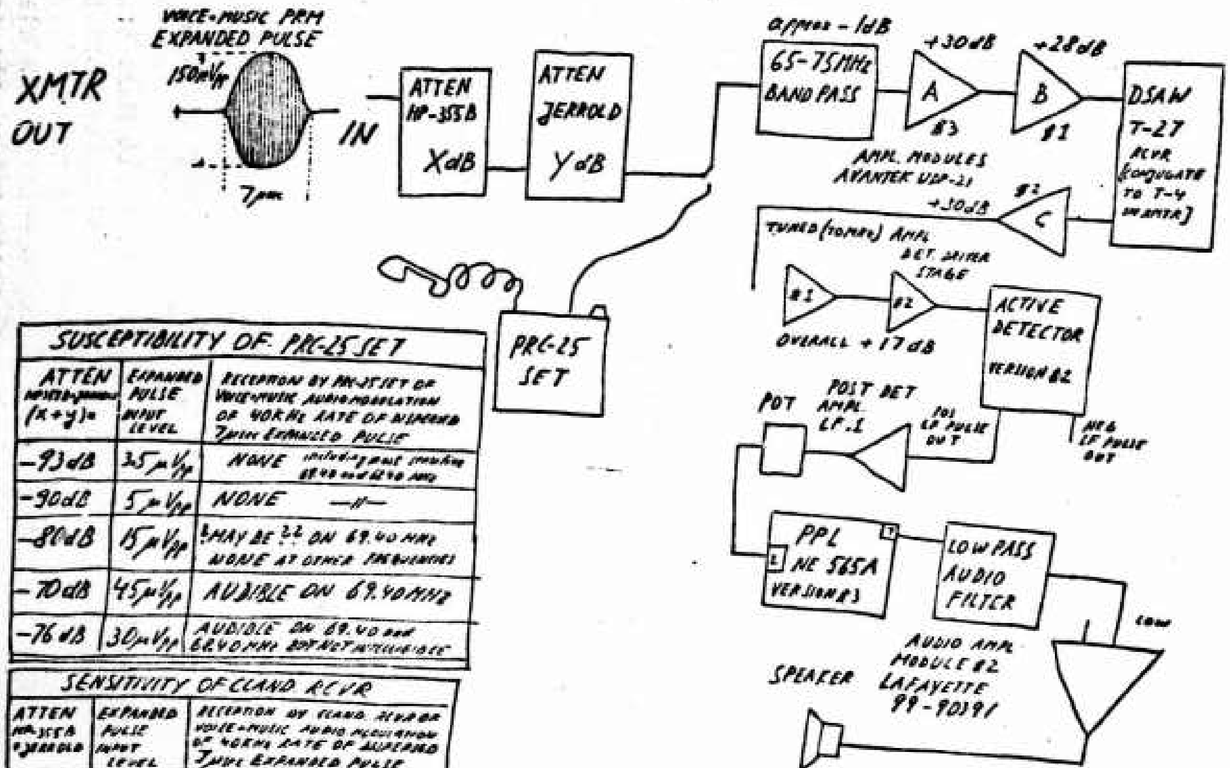


Fig. 10. Path of operator of PRC-25 plus whip receiver searching for clandestine transmitter,operating with 12-microwatts ON-OFF tone via TV antenna from Bldg. S-29.
At Locations A and B, appearance of periodic audio noise quieting. At Location C, about 6 meters from TV antenna feedline, received clear ON-OFF tone
(Evans Area).

be able to detect the clandestine transmissions from Bldg. S-29, even when operating their radios practically within reach of the clandestine transmitter. Yet, clearly-audible-tone and intelligible-voice signals were received from this transmitter by the clandestine receiver in Bldg. 6, 200 m away. The operation of the clandestine system is quantified best in terms of the intrinsic performance characteristics of System Version 6, in which cables were used to connect the transmitter and receiver (see Fig. 11). (In this version, the deteriorating effects of antenna impedance mismatch, noise, and nonlinearities--produced by the RFI that saturated the receiver--did not affect the operation of the receiver.) Clear voice- and music reception via cable was achieved at a 5 μV peak-to-peak level of the expanded pulse at the receiver input. Voice reception remained intelligible when the level of the expanded input pulse was reduced to 3.5-microvolts peak-to-peak. The following describes the sensitivity of the clandestine receiver to the clandestine signal, as compared with the susceptibility of the PRC-25 Set that was used to replace the clandestine receiver in the same circuit. (Sensitivity of the clandestine receiver relates to the reception of clear, intelligible voice signals by the receiver, whereas susceptibility of the PRC-25 Set relates to the sensing of clandestine transmissions by an apparent variation in noise output from the PRC-25 Set, e.g., noise quieting.) Using the PRC-25 Set for reception, a possible hint of the clandestine signal transmission (in the form of a slight quieting in the noise output from the PRC-25 Set) could be detected only at 69.4 MHz, and that only after a very careful search of the 65 to 75 MHz frequency band and at a 15-microvolt peak-to-peak level of the input pulse signal. Ultimately, after the input pulse signals were raised to 25-microvolts peak-to-peak, audible, although unintelligible, signal outputs were obtained from the PRC-25 Set at 69.4 and 68.4 MHz. The resultant difference of 10 to 13 dB between the sensitivity of the clandestine receiver and the susceptibility of the PRC-25 reflects the pulse compression gain of the receiver's DSAW device. The theoretically derived pulse-compression gain of the receiver's conjugate DSAW device in this case was 18 dB. The lower 10 to 13 dB pulse-compression gain obtained in practice when the transmitter and receiver were connected by cables demonstrates that an ~6 dB signal-to-noise ratio is required for clear reception of voice signals.

However, when the system was operated with the TV antennas, this 10 to 13 dB gain could not be obtained, largely because of strong interference from TV Channel 4. In fact, this interference from TV Channel 4 was so strong that it saturated the receiver amplifier in the experiments with System Versions 1 through 4. During these initial experiments, saturation by RFI from TV Channel 4 was overcome by inserting an attenuator into the receiver antenna cable and by increasing correspondingly the transmitted signal power. Under these operating conditions, the functioning of the pulse expansion-compression method was checked out, and the related problems--such as leakage pulse suppression--were solved. However, the truly clandestine character of the system could be obtained only by suppression of the receiver-saturating RFI from TV Channel 4 (video carrier: 67.25 MHz; sound carrier: 71.75 MHz). This suppression was achieved in System Versions 5 and 6 by using a notch filter at the input of the receiver. The notch filter also suppressed the energy associated with the spectral components of the clandestine chirp-pulse signals at ~67.25 and ~71.75 MHz. Consequently, the sensitivity of the clandestine receiver to the susceptibility of the PRC-25 Set was reduced. The resultant sensitivity of the clandestine receiver was then only 6 dB to 2 dB above the susceptibility of the PRC-25 Set. The observed



SUSCEPTIBILITY OF PRC-25 SET

ATTEN (X+Y) =	EXPANDED PULSE INPUT LEVEL	RECEPTION BY PRC-25 SET OF VOICE-MUSIC AUDIO MODULATION OF 40KHz RATE OF ALTERED 7μsec EXPANDED PULSE
-93dB	3.5μV/pp	NONE [illegible]
-90dB	5μVpp	NONE —"—
-80dB	15μVpp	MAY BE ?? ON 69.40 MHz NONE AT OTHER FREQUENCIES
-70dB	45μVpp	AUDIBLE ON 69.40MHz
-76dB	30μVpp	AUDIBLE ON 69.40 AND 68.40MHz BUT NOT INTELLIGIBLE

SENSITIVITY OF CLAND RCVR

ATTEN HP-355A + JERROLD	EXPANDED PULSE INPUT LEVEL	RECEPTION BY CLAND. RCVR OF VOICE-MUSIC AUDIO MODULATION OF 40KHz RATE OF ALTERED 7μsec EXPANDED PULSE
-86dB	7.5μVpp	AOK CLEAR
-90dB	5.0μVpp	OK CLEAR
-93dB	3.5μVpp	NOISY BUT INTELLIGIBLE
-96dB	2.5μVpp	AUDIBLE NOISY

T-27: Net loss 22 dB; CW loss 37.5 dB;
Pulse compression 15.5 dB

Fig. 11. Susceptibility of PRC-25 Set versus sensitivity of clandestine receiver to voice and music transmissions by rate (40 kHz) modulation of expanded pulse in closed circuit transmitter-receiver setups (Version 6) (Bldg. S-29, Evans Area).

changes in the sensitivity of the clandestine receiver relative to the susceptibility of the PRC-25 Set depended on the levels of time-variable local noise and RFI at the receiver site and also on the care used by the transmitter operator in avoiding overlap of the chirp-pulses by overmodulation of the transmitter's pulse-rate-modulation circuit. The 6 to 2 dB sensitivity of the clandestine receiver over the susceptibility of the PRC-25 Set was obtained with pulse rates within the 30 to 70 kHz range. The receiver's sensitivity increased up to 22 dB above the susceptibility of the PRC-25 Set when the system was used for the transmission of keyed audio frequency tones at a pulse rate as low as 1000 hertz using pulse amplitude modulation (PAM) instead of pulse rate modulation (PRM). The apparent increase to 22 dB, relative to the theoretically maximal 18 dB pulse compression gain by the receiver's DSAW device, is attributed to the lower susceptibility of the PRC-25 Set with respect to pulse amplitude modulated signals at the low 1000 hertz repetition rate. (The FM detection circuit of the PRC-25 Set is designed to suppress amplitude modulated noise.) Considering the overall performance of the clandestine system with the TV antennas, it is necessary to further point out that the optimal impedance match of these TV antennas to the nominal 50-ohm feed cables was at the 67.25 MHz and 71.75 MHz video and sound-carrier frequencies of TV Channel 4. The reactive impedances of these TV antennas and the imperfect impedance transformations at the other frequencies within the 65 to 75 MHz band also contributed to a reduction of the sensitivity of the wide-band clandestine receiver relative to the susceptibility of the narrow-band PRC-25 Set.

A significant part of the effort dealt with the elimination of detrimental effects from electromagnetic leakage through the DSAW device at the transmitter. In the initial versions of the system, electromagnetic leakage was suppressed by a specially devised leakage-pulse-suppression circuit at the transmitter. In addition to the efforts for suppression of the leakage pulse, an experiment was conducted in which the clandestine system (Version 1) served as the radio reference for the transmission and detection of low frequency signals which were transmitted by conduction through power lines and water pipes between Bldg. 6 and Bldg. S-29. In this case, the clandestine system was operated at a steady-state without audio modulation. (The significant improvement in the design and construction of the conjugate DSAW devices for System Versions 5 and 6 made the previously used leakage-pulse-suppression circuits obsolete.) Details of the experiments and of the specific circuits which were used in the different versions of the clandestine system are given in reference [6].

During the experiments with different types of RF to LF detectors, there arose the question whether the RF functions of the detector and the LF and audio stages could be accomplished by the PRC-25 Set. The operational advantages of such a union between the RF chirp-pulse compression section of the receiver and the standard FM man-pack set are self-evident.

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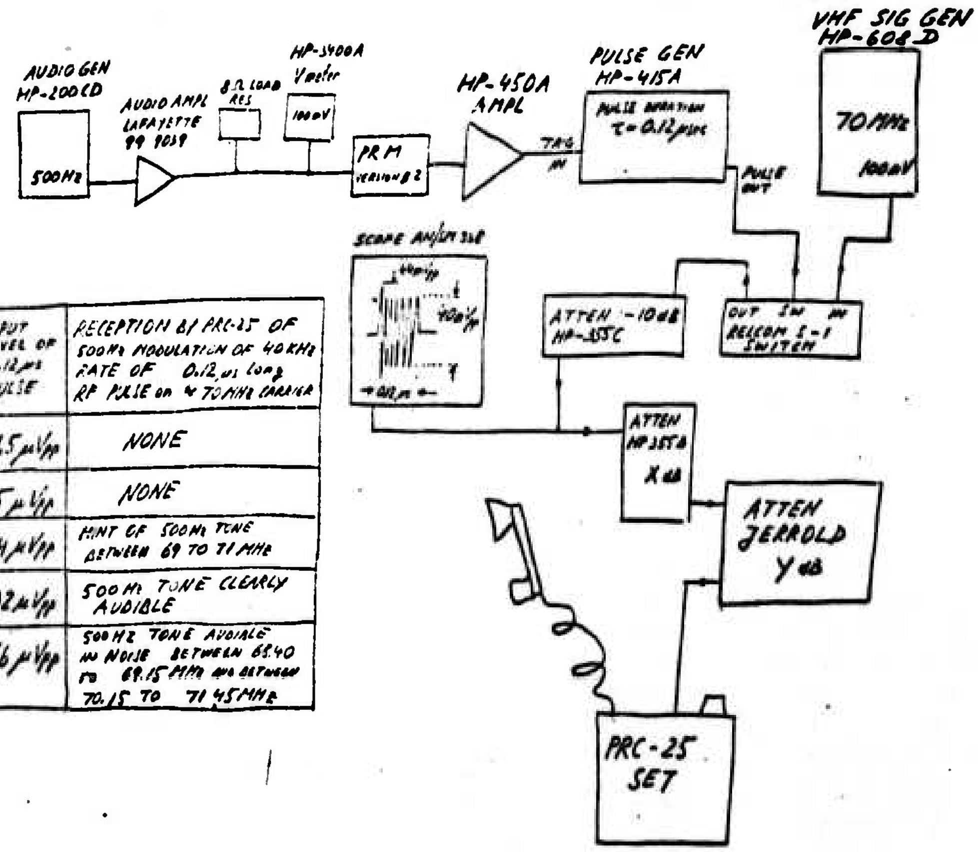
[6] K. Ikrath, W. Skudera, and C. M. DeSantis, "Short-range clandestine radio communications system," Technical Memorandum, Communications/Automatic Data Processing Laboratory, U. S. Army Electronics Command, Fort Monmouth, New Jersey, August 1976.

To obtain an answer to the question, the 50-ohm RF input of the PRC-25 Set was connected to the output of the RF section of the receiver. The receiver input was connected to the output of the transmitter by an RG-58 Cable and an attenuator. The transmitter, which was modulated by voice and by music, delivered a 200-millivolt peak-to-peak expanded pulse to the input of the attenuator which was set to 100 dB. At the resultant 2-microvolt peak-to-peak input level at the receiver, the RF section of the receiver delivered a compressed pulse output of 25-millivolts peak-to-peak above 10-millivolts peak-to-peak of noise. However, this approximately 0.1-microsecond long compressed pulse which was fed into the PRC-25 Set did not produce an audible signal. In fact, even after the attenuator settings were reduced to increase this pulse to 60-millivolts peak-to-peak, the response obtained with the PRC-25 Set was barely audible. The result was actually not surprising because the narrow-band (20 kHz) FM radio picked up only a small fraction of the energy from the 10 MHz wide spectrum of the compressed pulse. Consequently, the detector and limiter in the PRC-25 Set were controlled by steady-state noise, rather than by pulse transients. The negative result of this experiment was confirmed subsequently by direct measurement of the susceptibility of the PRC-25 Set to 0.12-microsecond long pulse spikes on a 70 MHz carrier frequency using pulse rate modulation by voice, music, and 500 Hz tone. The measurement setup and the test results are given in Fig. 12. Pulse spikes at levels of 44-microvolts peak-to-peak were required to obtain a barely-audible indication of the 500 Hz tone transmissions. The levels of these pulse spikes were two to three times greater than the levels of the expanded 6-microsecond long chirp-pulses which became noticeable with the same PRC-25 Set (Sec. G.5).

C. CONCLUSIONS

Different versions of a 65 to 75 MHz wide-band experimental chirp-pulse transmission system were used for short-range communications via TV antennas. The experiments were aimed at realizing a short-range (600-feet) clandestine voice communications capability for MOBA applications using <10 microwatts peak power. The operation of the experimental system and its comparison with a standard FM radio showed that the sensitivity of the clandestine receiver to voice transmissions by cable was 10 to 13 dB above the susceptibility of the PRC-25 Set (sensitivity defines the level for clear reception of voice by the clandestine receiver; susceptibility defines the level at which the PRC-25 Set begins to sense the clandestine signal transmissions by a change in its noise output, i.e., noise quieting). However, due to strong interference from TV Channel 4, the full potential of the clandestine system could not be realized when it was operated with the TV antennas. The use of a notch filter in the clandestine receiver eliminated the saturation effects by RFI from TV Channel 4, but at the same time reduced the sensitivity of the clandestine receiver to ~ 6 dB relative to the susceptibility of the PRC-25 Set. Thus, while a clear clandestine voice transmission capability via TV antennas was demonstrated, it was evident that a bandwidth of 10 MHz is too large to permit full exploitation of the clandestine system in the presence of strong interference, in our case, TV Channel 4. Furthermore, the 10 MHz bandwidth of the described versions of the experimental system was not compatible with the about 3 MHz wide bandwidth of standard military VHF antennas (e.g., the AS-1729/VRC). Consequently, the wide-band (10 MHz) DSAW devices which were used in the experimental system must be replaced by narrow-band (~ 3 MHz) DSAW devices. The system can then be modified accordingly to permit efficient operation with standard tactical VHF antennas.



ATTEN HP-355B + JERROLD X+Y.	INPUT LEVEL OF 0.12μs PULSE	RECEPTION BY PRC-25 OF 500Hz MODULATION OF 40KHz RATE OF 0.12μs LONG RF PULSE ON 70MHz CARRIER
−90dB	1.5μV/pp	NONE
−70dB	15μV/pp	NONE
−60dB	44μV/pp	HINT OF 500Hz TONE BETWEEN 69 TO 71 MHz
−50dB	132μV/pp	500Hz TONE CLEARLY AUDIBLE
−56dB	66μV/pp	500HZ TONE AUDIBLE IN NOISE BETWEEN 68.40 TO 69.15 MHz AND BETWEEN 70.15 TO 71.45MHz

Fig. 12. Susceptibility of PRC-25 Set to compressed 0.12 μs pulse on 70 MHz carrier (500 Hz tone transmission by pulse rate modulation). Bldg. S-29, Evans Area.

Regarding the benefits to be derived from the use of the clandestine system for MOBA, it has been shown that if someone is unaware that others are using a spread-spectrum communication system in a given area, the clandestine signal can be disguised very effectively in the radio noise environment of that area, even with the relatively primitive system used during these experiments. Furthermore, even if detected, the content of the signals would be very difficult to unscramble. One of the consequences of these characteristics, however, is that the operating range of the system is small, approximately 1000 yards or less. This should still be ideal for a system which must be operated in situations requiring street-to-street, street-to-building, etc., communications. It may not even be necessary to have a completely clandestine voice communication system. In fact, the study as originally conceived was meant to demonstrate the transmission and reception of yes/no, true/false, or go/no-go information, while simultaneously using normal radio communication channels to pass information in the form of questions or conditional statements. In this mode, it was virtually impossible to distinguish the clandestine signal, due to its short duration, from the background noise without the use of a conjugate DSAW filter. A simple, but effective, symbolic language could be created by using several DSAW devices, each with a slightly different dispersion characteristic, to represent the language symbols, so that even if detected, the information would not be compromised.

It is believed that the adaptation to present communication equipment of a clandestine system, such as the coded system just described, would be more feasible than even the simple voice system used in this study (which of necessity required a much more complicated circuit). A voice system, i.e., one which overcomes the difficulties discussed in this study, such as susceptibility to overload, would probably have to be implemented in the form of a self-contained transceiver.

A clandestine communication system, to be more effective for MOBA and at the same time to capitalize on the unique frequency propagation characteristics of a complex built-up area, should be designed to operate in a higher frequency band. At higher frequencies, smaller transceivers and smaller-sized antennas with inherently wider bandwidths could be achieved.

It is the belief of the authors that a simple clandestine system based on DSAW technology is practical and would be extremely useful for communication for military operations in built-up areas.

D. PROPOSALS FOR FURTHER WORK

D.1. Reduction of Bandwidth

To achieve compatibility with standard tactical VHF antennas, the reduction in the system's bandwidth from 10 MHz to 2.5 MHz is expected to also improve the operation of the system in the following additional respects: (1) Vertical polarization of the tactical VHF antennas used in conjunction with the smaller bandwidth is bound to significantly reduce interference from TV Channel 4, (2) Narrow-band DSAW devices are furthermore expected to have less insertion loss than the wideband devices used in the experimental system versions described in this report. As a consequence, less amplifier gain will be required in the narrow-band clandestine receiver, and (3) The lower gain of the narrow-band clandestine receiver is bound to reduce its susceptibility to saturation by RFI from vehicle ignition circuits, electrical machinery, and from other radio sources.

D.2. Suppression of RFI in Narrow-Band Systems

In the 10 MHz wide-band experimental system, high-level RFI from TV Channel 4 was eliminated in the receiver by inserting a notch filter. However, this notch filter also suppressed the spectral components of the chirp-pulse signals at and around the video- and sound carrier frequencies of TV Channel 4. The loss of these spectral components from the 10 MHz wide spectrum of the chirp-pulses lowered the performance of the system. The resultant lower performance was still tolerable for clandestine communications in the presence of standard FM radio sets. Yet, in the case of a 2.5 MHz wide spectrum for the chirp-pulses, the loss of spectral components from these pulses by means of a notch filter would become intolerable. Consequently, the suppression of high-level interference in the narrow-band system (2.5 MHz) by means of a notch filter would make the system inoperable. In this case, the removal of high-level interference and the preservation of the spectrum of the chirp-pulse signal could be achieved by nonlinear limiting of the RFI at the front of the receiver. Such a limiter, with low insertion loss, could be adjusted to clip the RFI above the level of the chirp-pulse signal while passing the energy of the signal. The remaining RFI power level would then have the same peak level as the chirp-pulse signal. However, unlike the chirp-pulse, the remaining RFI would not become compressed by the DSAW device in the receiver. Instead, this RFI would become further dispersed, i.e., decorrelated relative to the chirp-pulse signal spectrum. Thus, the full effectiveness of the DSAW device could be realized for the enhancement of signal-to-noise by pulse compression.

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