SINGLE RF CARRIER TIME-SHARING BY REMOTE LOCATIONS

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Summary It is of vital national interest to know the essential real-time factors involved in the evaluation of an air attack versus a ground defense. This need led military planners to request the development of a computerized system to determine the victors and the vanquished in a war game on a par with an actual combat situation. From an engineering point of view, the evaluation system would permit all "combatants" full scope of operation and would not introduce, of itself, any "artificialities" into a complexity of split-second duels taking place over a wide geographical area. This paper discusses a unique time-division telemetry technique that was designed to resolve the data and control flow to and from remote locations, in this case, tactical aircraft. The actual system that evolved from this approach transfers all "aim and fire" events, coming from a group of aircraft engaged on a "mission", to a central communications and data processing facility. The control in the form of timing synchronization is sent from the facility to all aircraft. It should be noted that this time-sharing method could not utilize classical time-division multiplexing, e.g., PAM or PDM, since the test elements were all physically separate from one another (up to 120 miles). Preliminary test data is presented herein as an indication of the validity of this new technique. The paper concludes with a brief description of this method as applied to air and water pollution control and other posited applications.

Introduction Figure 1 is a simple conceptualization of the dispersal of ground and air elements and how they relate to the central facility which evaluates and determines the effectiveness of test elements while actively engaged. The weapons system consists of 15 tactical aircraft (airborne elements) and 10 ground-to-air missiles (ground elements). This computerized communications facility receives all telemetered data, and, by a programmed comparison of all real-time variables (including hits and misses), decides who has won and lost specific engagements. The participants in specific battles are informed of the outcome by means of an RF link. Obviously, a "dead" element cannot go on with the fray. Ground-based telemetered data from missile positions involve aim-and fire parameters such as weapon elevation, azimuth, position (derived from a Decca hyperbolic navigation system), time of firing, and so on. Telemetered data from an aircraft relate to altitude, attitude, airspeed, azimuth, position (also from a Decca system), time of weapon firing, etc. The characteristics of the different type weaponry as it relates to typical projectile trajectories, accelerations, velocities, and kill radii are stored, in advance, in the computer memory.

The air weapons system occupies a circular zone of 11,300 square miles, with the communications and data processing facility at the central point. Each airborne element at any random placement within the test range, transmits data to the receiving station (ground zero) at a distance from 0.25 to 60 miles. It was found not desirable to allocate a separate frequency to each element since air weaponry would be using an RF band of which many frequencies were already reserved for other purposes. Furthermore, only one ground receiver, instead of 15, would be required. A single frequency in the L-Band was therefore selected for use by all airborne elements, but governed by the rule that each aircraft would transmit during an assigned period over the commonly shared carrier. Since the frequency band allocated for the ground elements was 30 to 40 MHz, a separate channel for each such element was required due to the limited information capacity of a single channel in this frequency band. A separate receiver at the communications center was permanently assigned for monitoring each ground element. The data from all time-shared airborne elements and individual ground elements are demodulated and routed to the multiplexer where it is placed in proper format for processing by an IBM 360/65 computer. Thus, the data as it is being received from all the elements occupied in simulated firefights are being “decided” by a set of complex programmed causes and effects equal to the realities of: who fired first, what weapons were fired, where they were aimed, the kill effect of all projectiles, and so on. In addition to notifying each winner and loser “on the spot” of the outcome of every engagement, individual weapons used by their human operators are also evaluated. For example, when a combatant “fires” his weapon too soon or out of range of his target, an automatic printout takes place at the computer which has a program store of weapons characteristics including range. At a later time, this information is distributed to all concerned parties to help in assessing individual weaponry skill. Thus, in all aspects, the factor of human judgment with its fallible nature is eliminated. In the past, skilled specialists could effectively evaluate the outcome of a conventional war game; however, with today’s advanced military equipment of enormous striking power within a highly curtailed time frame, it is beyond unaided human observation to assess the actualities, in whole or in part.

Statement of the Problem At the time of design review for the time-shared portion of the program, the following technical questions had to be answered before the adopted scheme could be implemented:

1. What is the most economical and effective method of synchronizing element transmitters to permit proper data transfer into assigned time slots?

2. What amount of guard time is necessary between element transmissions to prevent overlap of data?

3. Does the required number of data samplings exceed the limits of the adopted scheme?

4. Can a standard off-the-shelf telemetry receiver be used ? Must it be modified? If either choice is not possible would the characteristics of even a specially designed receiver be such as to make the time-sharing mode of operations unfeasible?

The major paragraphs that follow are in the same order as the questions listed. They comprise the analyses and results that were obtained in the course of implementing the time-sharing technique. The technical features and problems arising from the use of multiple transmissions on a time-shared basis are developed, including time synchronization, propagation, reception characteristics, and equipment configuration. Figure 2 shows, in simplified block diagram form, the actual system which met the design requirement of L-Band data encoding and transmission on a single frequency for fifteen airborne elements responding in a “round robin” fashion to a central communications and data processing facility.

Time Slot Synchronization An external means of synchronization utilizing an uplink was selected to synchronize the data flow on the common downlink from each of the fifteen airborne elements; thus, data from each element is inserted, in turn, in the same position of every frame. Although an extremely stable frequency source carried on board each plane could also have been used for this purpose, its distinct disadvantage would be that the frequency source of each aircraft would have had to be present prior to each flight. The better means is the use of a common radio uplink carrying sync to all aircraft from a centrally located ground-based source. The synchronization for continuous updating of the equipment in the airborne elements is received during all test periods on the uplink which had already been provided for other purposes. The initial requirement was to provide a “kill” notification to “shot down” aircraft so that the pilot knew he had to leave the test area. The function of the link was extended when it was found possible to control the periodicity of kill and other data being transmitted to include sync or timing data. The information on the uplink, known as the kill/time code, is organized into a format of ten data and identification words as shown in Figure 3. A modified form of IRIG Standard Time Format B is utilized. The transmission of the kill/time code is synchronized by a time-code generator located in the central facility. The time frame requires one second since each word occupies 100 milliseconds. Timing data is made available to each airborne element by inserting appropriate position identifiers between words and at the start of each frame.

The original decoder in each aircraft handling pilot information coming over the uplink, which was modified to include timing to synchronize proper time-slotted transmissions, was renamed the “kill/time” decoder.

If an uplink had not been intended to be part of the program, and for some reason, it was impractical to implement, then stable frequency sources would have had to be installed on each aircraft. Further investigation of this alternative was not carried out since the existing uplink could be used. Without having performed this study, it is safe to say that such an alternative would have presented far greater technical design and implementation problems; and even beyond this, would have been more costly.

Guard Time The factors involved in calculating guard time requirements are shown in Figure 4. Guard time takes into account propagation delays, equipment turn-on and turn-off times, and equipment delay times. If sufficient time for this purpose is not worked out in advance, distorted or unusable data due to transmission overlap by aircraft using adjacent time slots will occur. For this reason, the propagation and delay data for establishing the program’s guard-time specifications had to be very carefully investigated.

All aircraft transmitters utilize frequency modulation on an assigned frequency in the 1435 to 1535 MHz telemetry band. The data transmitted from each aircraft is in digital form; specifically, serial PCM-NRZ-C (Non-Return to Zero-Change). The carrier is premodulation filtered to reduce transmission bandwidth requirements. Each aircraft transmits its PCM/FM signal at a period controlled by the kill/time decoder for a maximum of 5.1 milliseconds. Thus, each airborne element on this time-sharing basis dovetails into its own specific time slot as shown in Figure 5. A maximum transmission bit rate of 80 kilobits/second was selected and new information bursts from all 15 aircraft are received every 100 milliseconds or the length of a frame word. The guard time of 1.66 milliseconds maximum between emissions from each adjoining element in the timeshared plan prevents data overlap as described in the following paragraphs.

The derivation of guard-time requirements depends on an understanding of how the kill/time decoder in each aircraft utilizes synchronization for its role in the time-sharing system. Each kill/time decoder of a specific element, programmed to provide the gate signal for turning on the ‘RF carrier at the proper time, is referenced to its particular time slot by means of the time format (Figure 3), received over the uplink. With the exception of propagation and equipment delays, each decoder receives this kill/time code at the same time, permitting establishment of 15 transmitter slots for the time-sharing program. An internal clock in each decoder provides the timing that plays so large a part in gating an associated aircraft RF transmission to the appropriate word slot. The clock is updated every 100 milliseconds by means of the timing data received over the uplink from a time-code generator located in the communications center. The generator is maintained accurately by comparison with station WWV and the local Loran-C chain.

The individual slots of the time-sharing scheme could be maintained without a local synchronizer installed in each time decoder, if pulses were always received over the uplink. Since in actual practice, this cannot be realized, a local clock in each kill/time decoder had to be provided to maintain synchronization during expected short propagation outages. Thus, in the absence of an updating format, the decoder will continue to gate the L-Band transmitter up to a maximum of 99 seconds, the worst-case condition. During any outage, timing will continue from the last-received usable signal. In this way, the effect of short-propagation outages, a difficult matter to preclude in L-Band airborne operation, is thereby negated and proper time slot allocation is ensured during the outage. Smooth pick-up of timing, once the incoming timing pulses can again be received, is also accomplished by this method. The greater the guard time, the further out an aircraft can be before its data will overlap data in an adjacent time slot. Also, the greater the distance, the weaker the received signal power at the central facility and, therefore, the probability is higher that the received signal power of the desired data is sufficient to override the overlapping data. Propagation delay was calculated for 60 miles, the maximum called for by system specifications. Computations relating to guard time, if overlapping occurred, show that the received signal from the closer aircraft (since both transmitters are of identical make and power) would be at least 3 db higher than that of the other aircraft; therefore, the discriminator of the FM ground receiver would be captured by the higher power signal. Propagation delay was computed based on an TIF carrier traveling at 186,280 miles/second. For a 60-mile distance, maximum one-way delay was found to be 322 microseconds. The two other factors that contribute to the guard-time requirements were then considered. Firstly, the time required for transmitter carrier power to decay after the removal of the gate signal is dependent on the inherent delay of the switching diode controlling RF transmission. Typically, this diode takes from 25 to 100 microseconds to change state. Although worst-case transmitter carrier power decay has been measured at 100 microseconds, 25 to 50 microseconds is the more common. For carrier power decay in actual transmitters, a maximum spread of 75 microseconds was allocated in the guard-time calculation. Secondly, circuit delay times are also present to a varying degree in each actual aircraft receiver and kill/time decoder. Under worse-case conditions, time delay for a pulse starting at the receiver input and going out as a gating signal from the decoder totals 250 microseconds. The receiver delay is 200 microseconds, most of which is due to the output stage bandpass filter (centered at 1000 Hz) and the other 50 microseconds is due to the kill/time decoder. Worst-case deviation of time delay, by using different receiver and decoder combinations of the same type models in random equipment checking, was found to be 125 microseconds. Overall worst-case deviation can be conclusively stated as being 200 microseconds; wherein, 125 microseconds is taken up by the kill/time decoder and receiver combinations, and the remaining 75 microseconds by transmitter power decay time.

It can be seen from Figure 5 that the parameter which most seriously affects time synchronization is propagation delay. The worst-case situation occurs when one aircraft is maneuvering within a 60 mile radius and a second is doing the same at 0.25 miles. When both aircraft kill/time decoders are updated, element number 1 decoder clock will be lagging number 2 by about 321 microseconds, the time it takes the RF energy to travel 59.75 miles. By the same reasoning, aircraft number 2 transmissions will reach the central facility, 321 microseconds before those of number 1, causing the two aircraft to be 642 microseconds out of synchronization. This situation does not cause data overlap, even including the worst-case consideration of a 200-microsecond circuit delay, since the total allowable delay time that was provided for the system is 1,660 microseconds.

During design exploration for a suitable ground receiver configuration for the airborne elements, it was not certain whether AFC and AGC response times for the receiver would have to be included. When it was proven that neither AFC nor AGC was necessary, these response times were eliminated from guard-time calculations. (Refer to the paragraph, Receiver Characteristics, of this paper which discusses the tests that were performed in this area.

To summarize guard-time requirements: the worst-case lack of synchronization between adjacent element transmissions is caused by two-way propagation delay lasting 642 microseconds plus an additional worst-case circuit-time delay of 200 microseconds for a total of 842 microseconds. The remaining 818 milliseconds is a safety margin, which has been shown to be adequate since no discrepancies due to data overlap have yet occurred during actual system usage.

Data Sampling Requirements Since data sampling requirements had been established by program management, the author did not undertake any investigations in that direction for the actual system to be implemented. When determining these requirements for a specific application, the capacity of the communications link must be investigated to verify that it can accommodate all of the data. The sampling rate is one of the most critical factors in deciding whether the timesharing technique is suitable for a contemplated application. The basic sampling rate equation for a single-carrier time-sharing plan is:

$$S_r = \frac{t_d}{nt_d + nt_g}$$

Where: t_d = data time for one element
t_g = guard time between elements

n = number of elements

Note: Frame Time equals $nt_d + nt_g$

Applying the preceding equation to the weapons evaluation system, its sampling rate is found to be:

$$S_r = \frac{5msec}{(15)\ (5msec) + (15)\ (1.66msec)} = \frac{1}{20} \text{ or } 5\%$$

In certain applications, a sampling rate of five percent might be cause r abandoning a time-sharing approach; however, for the system described, this rate was quite acceptable. In the system under review, it should be noted that this sampling rate refers to the total data from a single element. Each five-millisecond data burst additionally includes multiplexed data from fifteen sensors aboard each aircraft. Thus, the actual sampling rate of each sensor averages 0.33 percent -- a rather low rate. It can be concluded that the time-sharing plan is limited by the relationship of the maximum sampling rate available to the data transfer requirement for a particular scheme.

Receiver Characteristics Conscientious engineering concerns prefer to recommend standard off-the-shelf products, even with some modifications, if necessary, rather than suggest a usually costly R&D effort to match a particular requirement. This thinking entered into the procurement for the ground facility telemetry receiver. At the onset of the program, it was suspected that some modifications to existing receiver circuitry would be sufficient to accommodate the hardware to the time-sharing scheme. The following paragraphs review the results of this exploration.

AGC Feature Automatic gain control can be critical in a time-shared system with mobile transmitters because of the variations in received signal level from one element to the next. In the weapons evaluation system, since elements can be as close as 0.25 mile from the ground receiver or as far as 60 miles, a difference in received levels of about 48 db can be expected. Consequently, if AGC was incorporated, the AGC circuitry would have to respond rapidly to accommodate changes in dynamic range so that no data would be lost whenever a transmission from a nearby element was followed by one from a distant element. Note that this is a particularly stringent case since the AGC of the receiver would have to respond, in turn, and in close order, to a strong signal followed by a low-power signal. The consequence of poor receiver AGC response, if it had been .used, would have led to the unacceptable situation of some data loss at the beginning of each burst. The bit synchronizer, inputted from the telemetry receiver, requires the first three words of “clock” to lock onto a signal to ensure no subsequent information loss.

A typical data format for an aircraft element is represented in Figure 6. Each five-millisecond burst consists of twenty-five words of sixteen bits each. The first three words of each frame are allocated to clock pulses. Forty-eight bits of clock, at the beginning of each frame, are provided for bit synchronizer lock-on following reception at the central facility. Following the three clock words is “frame sync,” in modified Barker Code, that is required to prepare the computer multiplexer for the data that follows. This multiplexer transforms the serial data output of the bit synchronizer into 8-bit bytes required by the computer input. The fifth word in the data format includes both element identification and data, and the remaining twenty words are data only.

Standard product-line telemetry receivers were examined to find, if possible, a better-than-average AGC response that would not cause the guard-time limit to exceed 1,660 microseconds. A telemetry receiver with a specified AGC response of 750 microseconds and a one-millisecond decay time was obtained. Tests of its AGC showed that the actual response stayed within the 750-microsecond limit, but its decay time was much worse than expected. Adjustments of this decay time, although attempted, showed little promise of achieving the necessary performance. At this stage, it became questionable that the time-sharing technique was feasible. It was decided to check receiver performance by means of tests utilizing such program end-items as an L-band transmitter, a data encoder, and an L-band receiver. A bread-boarded test simulator was quickly assembled. Figure 7b shows a 100-millisecond data frame at the receiver output with simulated data that was applied in only slot number one to simplify matters. Figure 7a indicates the AGC decay time of the particular receiver used. An expanded view of the test data is shown in Figures 7c and 7d. It is evident that any data appearing in the second through the fifth slots would be degraded, if the number one data burst was a strong signal (as it was during this test) and data bursts two through five were weak. The initial bunched pulses in the lower trace simulate clock and the sync word. The remaining words are indicated by means of their parity bits.

Figure 8 shows the results of testing with receiver AGC turned off. The time scale has been expanded to show the first few words in greater detail. The upper trace, Figure 8a, is the data signal before modulation by the transmitter. The bottom trace, Figure 8b, shows receiver data output without AGC. The data shown was somewhat distorted by the receiver output filter. This test demonstrated that the receiver responded properly to strong incoming signals when the receiver AGC was set to the manual or non-AGC mode.

The aforementioned experiments showed that: (1) normal receiver AGC can cause intolerable loss of data in the system, and (2) AGC is unnecessary because the receiver responds to incoming data after a period of noise without loss of data output. Therefore, AGC for use in the time-sharing system under implementation was discarded.

AFC Feature Automatic frequency control is normally employed when the received frequency is expected to drift at a relatively slow rate, due to such reasons as transmitter instability or Doppler shift. With or without AFC, it is important to design a receiver with the least possible IF bandwidth to increase receiver noise immunity. For most cases, a method of drift prevention is used to prevent signal loss. Automatic frequency control is relatively simple to implement when the carrier is continuously being received from a single transmitter having slow-frequency drift. The receiver is properly designed so that its AFC tracking range is made greater than the IF bandwidth by a worst-case factor of drift that will be encountered. The use of AFC is more difficult in any timeshared system since the frequency of incoming signals between adjacent data bursts changes as a step function in comparison with frequency changes due to instability. Figure 9 shows a typical receiver discriminator curve where f_1, f_2, and f_3 represent the frequency ranges of three adjacent elements whose transmitted carriers have been displaced from one another due primarily to individual transmitter frequency inaccuracies and instabilities. Note how this illustration demonstrates the dc offset occurring because of frequency differences between the three elements.

The dc offset in time-shared data from a discriminator output, caused by frequency instabilities, can be eliminated if a sufficiently rapid AFC response can be applied. It should also be pointed out that dc offset, when exceeding limits usually more than 100%, can cause errors in the bit synchronizer being fed by the receiver. The bit synchronizer is basically used to regenerate both noisy and premodulation-filtered digital data inputs. In the early design phase of the specific time-shared weapons system, a maximum de offset well within the range of the bit synchronizer capability was estimated.

Laboratory tests of prototype communications equipment were performed after the design stage of the program to determine the feasibility of AFC for the timesharing scheme. The stability and accuracy of the prototype L-Band transmitters, built to rigorous military specifications, exceeded expectations since the worst-case de offset possible for the system was found to be less than half of the 74% that had initially been calculated. The AFC circuitry of the preferred standard telemetry receiver selected for the system, however, was not able to respond, without loss of data, to the sharp changes in frequency presented by the timesharing scheme. The 500-microsecond AFC response time of this receiver, equal to 10% of the total data burst time, was an intolerable situation. Therefore, AFC could not be usefully employed in curbing the-dc offset problem.

Testing of standard telemetry receivers proved that AFC was not required. Apart from the fact that less worst-case de offset was obtained with the actual transmitters, the nature of ac coupling used in the receiver further attenuated de offset. From the reception point of view, this attenuation is dependent on the actual time between received data bursts and the time constant of the receiver output circuitry. The small probability that one element at one extreme frequency deviation will be followed by an adjacent element at the opposite extreme is an additional aid. (An example of an extreme case would be where element 1 caused a =0.006 de offset excursion, followed by element 2 with a

-0.006 de offset excursion.) At the very beginning of the weapons evaluation program, stringent specifications were established for the receiver and transmitter oscillator tolerances, since the receiver's AFC response was a questionable matter.

IF Bandwidth Table 1 lists the parameters contributing to the receiver IF bandwidth which was chosen. Unless otherwise noted, frequencies shown were calculated for a carrier frequency of 1500 MHz. The items marked with a single asterisk (*) contribute a steady frequency bias to the discriminator, while those marked with a double asterisk (**) cause de offset between element data bursts. It was determined that a 300-kHz IF bandwidth is sufficient, allowing for parameter instabilities and energy content in the spectrum used. This choice has proven to be correct in the actual use of the system.

When it became apparent that AFC could not be used, the original selection of a standard IF bandwidth was shown to be best for obtaining maximum information with least bandwidth.

Summation In other system applications, it is possible that the AFC and even AGC features may be usable. The dictates of a particular system configuration will determine the designer's response in this area in terms of selected equipment and data requirements.

Table 1. Receiver Bandwidth Considerations

Parameter	Range	Frequency
Transmitter Deviation	---	± 150 kHz
Transmitter Oscillator Stability	±0.003%	± 45 kHz**
Transmitter Oscillator Accuracy	±0.003%	± 45 kHz**
Doppler Shift for Aircraft Velocity	1500 mph	± 3.3 kHz**
Receiver First Local-Oscillator Stability	±0.0001%	± 1.5 kHz*
Receiver First Local-Oscillator Accuracy	±0.002%	± 30 kHz*
Receiver Second Local-Oscillator Stability	±0.005% of 40 MHz	± 2.0 kHz*
Receiver Second Local-Oscillator Accuracy	±0.005% of 40 MHz	± 2.0 kHz*

* Causes steady bias of discriminator output
** Causes offset between messages

Other Possible Applications The author wishes to take this opportunity to touch upon other important probable uses of the time-sharing technique, utilizing this basically simple method of obtaining data from remote locations scattered over a large area. It is beyond the author's expertise to attempt (except for a missile test range described subsequently) to postulate further aerospace applications.

In the area of industrial or public use, the time-sharing technique is particularly applicable to systems with fixed remote stations scattered over a large area, where data of a slowly varying nature must be transferred to a central monitoring and control facility. This application shows great promise for water and/or air pollution monitoring systems for large cities, or even on the state level, where a number of remote sensors collect data on all strategic points for transmission to a centrally located data processing facility. See Figure 10. This deep concern for the public's health and recreation is attested by the fact that several local governments have already queried the author's organization on how to implement effective pollution control. The scheme involves a number of sensors gathering data on current changes in levels of specific or combined noxious pollutants in air and/or water. The data would then be transmitted to the central facility where the transmissions are demodulated and the pollution data formatted, routed to a computer, and compared with associated pollution index guidelines stored in computer memory. Whenever these levels were exceeded for a particular pollutant at any remote location or group of such locations, then an immediate counterresponse could be undertaken by the authorities in charge of the program. The sensors could be distributed in an equal fashion to monitor a general region, or sensors could additionally be concentrated at known points that are critical to the general health. As soon as any known safe level was found to be exceeding medically established norms, then the center could alert the authorities to take remedial measures to eliminate or reduce the hazard before it became even more critical.

Recent news headlines have dramatized the destruction of water life and the fouling of beautiful seashore resort areas. Water pollution has always been of particular concern in coastal areas, where oil or other noxious substances, dumped illegally by freighters, wash up on nearby beaches. A pollution monitoring system using the time-sharing technique described in this paper could be utilized to immediately alert the Coast Guard to a sharp increase in pollution levels so that the authorities could react quickly against such violators, and by only a few being brought to justice, illegal waste dumping would be considerable reduced. Similar tactics could be used to save fishing streams, water fit for human consumption, and other vital water sources too numerous to list.

Another use of the time-sharing technique would be an earthquake early warning application where many remote sensors, even on a national or continental basis, are employed to transmit data to a central facility. The sensors are placed at known locations where minor tremors or terrain shift along “faults” in the earth’s structure are harbingers of more serious trouble to come.

The time-sharing technique for high-velocity projectile applications similar to the one described in this paper can be used to provide timing and data to test range ground stations. A typical test range has a number of distributed monitoring stations that require timing data to remain in synchronization with the main facility, so that when a missile is fired downrange, accurate measurements of its velocity and other related factors can be achieved. Where data is required for each downrange station, it can be multiplexed onto the timing information similar to the modified IRIG B used in the weapons evaluation system. A decoder at each station would then select the data applicable to that station and furnish the required input in the appropriate form to the associated station instrumentation.

In the postulated usages, the time-sharing technique permits use of a single frequency and one receiver at the central facility in apposition to a conventional radio system which requires a separate frequency and receiver for each monitoring point. In a situation where thirty to forty or more remote stations are involved, the economic advantage of the time-sharing system becomes considerable. With such parsimonious use of the frequency spectrum and costly equipments, many necessary scientific or public-serving programs now held back by economic factors may be ushered in.

Conclusions The results of the time-sharing technique applied to the weapons evaluation program demonstrate that the technique can be utilized among physically separated discrete remote locations telemetering important information to a central receiving facility. This method permits a considerable simplification in frequency allocations and associated communications equipment needs. It lends itself to great advantage where physically separated elements, moving or fixed, must transmit to the same receiving location at data sampling rates that are not excessive. Distances do not become a factor if the guard time between element transmissions is properly established.

Two basic methods for time synchronization to maintain each transmitting element in its proper time slot are available. One is the use of a self-contained and accurate time source for each transmitting element; or two, the use of a link for transferring timing from a centrally located time source. In the weapons evaluation system, the latter alternative, as the more efficient method, was a foregone conclusion since a link was already available for other purposes. Depending on the format of the data on the link, it may not be a difficult matter to alter the programmed data of an existing link to include timing, control, data correction, etc.

Evaluation of data requirements for an actual system showed that the sampling rate permissible under the time-sharing plan was realistic. The sampling rate varies inversely with the number of elements and the amount of guard time required to prevent overlap of data. In the system, the guard time was found to be approximately one-third the data transmission time from each element.

Another benefit achieved by the plan was that a standard off-the-shelf telemetry receiver requiring no modification was incorporated in the time-sharing scheme. AGC and AFC were not used because the variation in signal strength and frequency between adjacent data bursts demanded an excessive response from the receiver control circuitry. By careful attention to system design, including such items as transmitter and receiver stability, guard time, time synchronization, receiver bandwidth, etc., proper operation under all required conditions was ensured. It is recognized, however, that AGC and AFC considerations will have to be examined anew in terms of the specific communications equipment to be made available for other contemplated applications.

In conclusion, even though the time-sharing plan described in this paper was applied to a weapons evaluation program, the technique is applicable to any project where geographically separated elements must report to a central receiving and data processing/ control facility. With minor engineering modifications, the scheme could also be used in conjunction with a central transmitting facility sending multiplexed data on the same frequency to physically separated locations, with a data burst in an assigned slot for each remote receiving element, in an equal but opposite manner to that which has been described. The author has outlined some challenging possibilities in air/water pollution, earthquake sensing, and downrange missile tracking applications. He eagerly awaits further extensions using a single ‘RF carrier time-sharing technique, since it offers such a low-cost, definitive telemetering means for extending man’s knowledge and control both for the national defense and for the general benefit to the public at large.

Acknowledgements The author wishes to particularly thank Mr. Carl N. Pavone of the Raytheon Company for his technical perspicacity and conviction that the time-sharing approach would prove to be a workable technique for the weapons evaluation system.

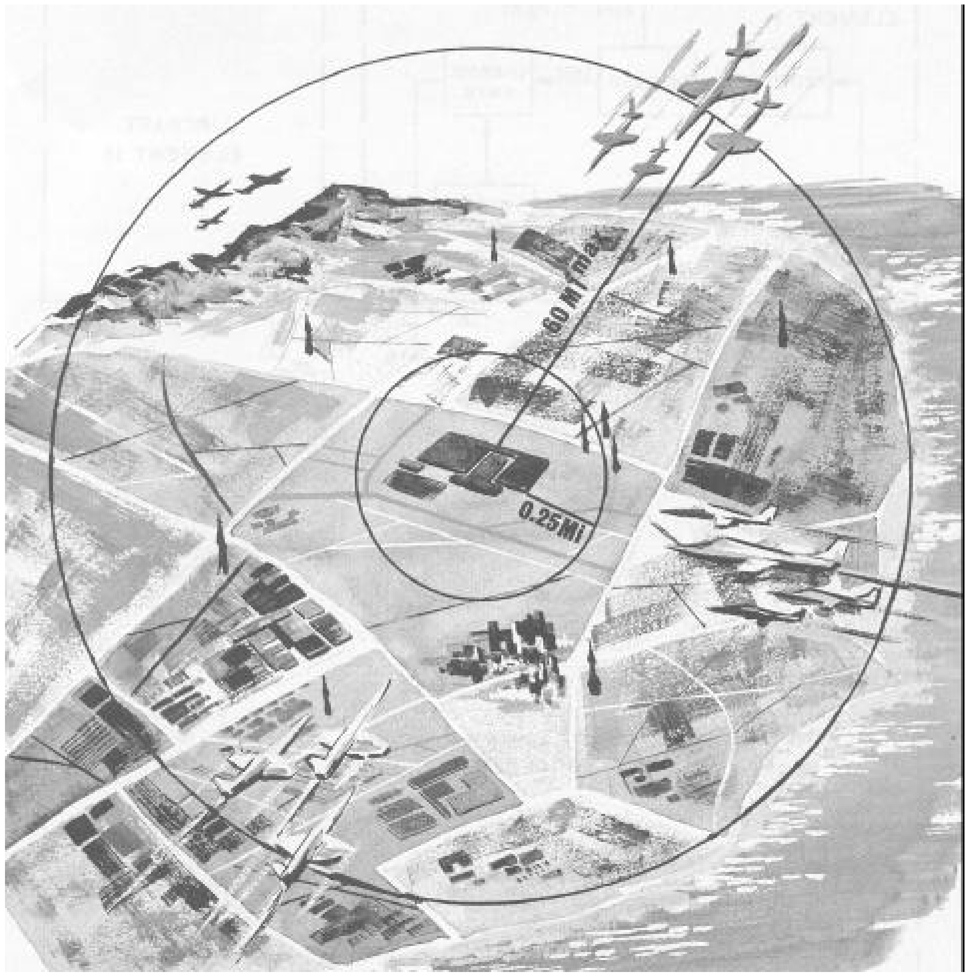
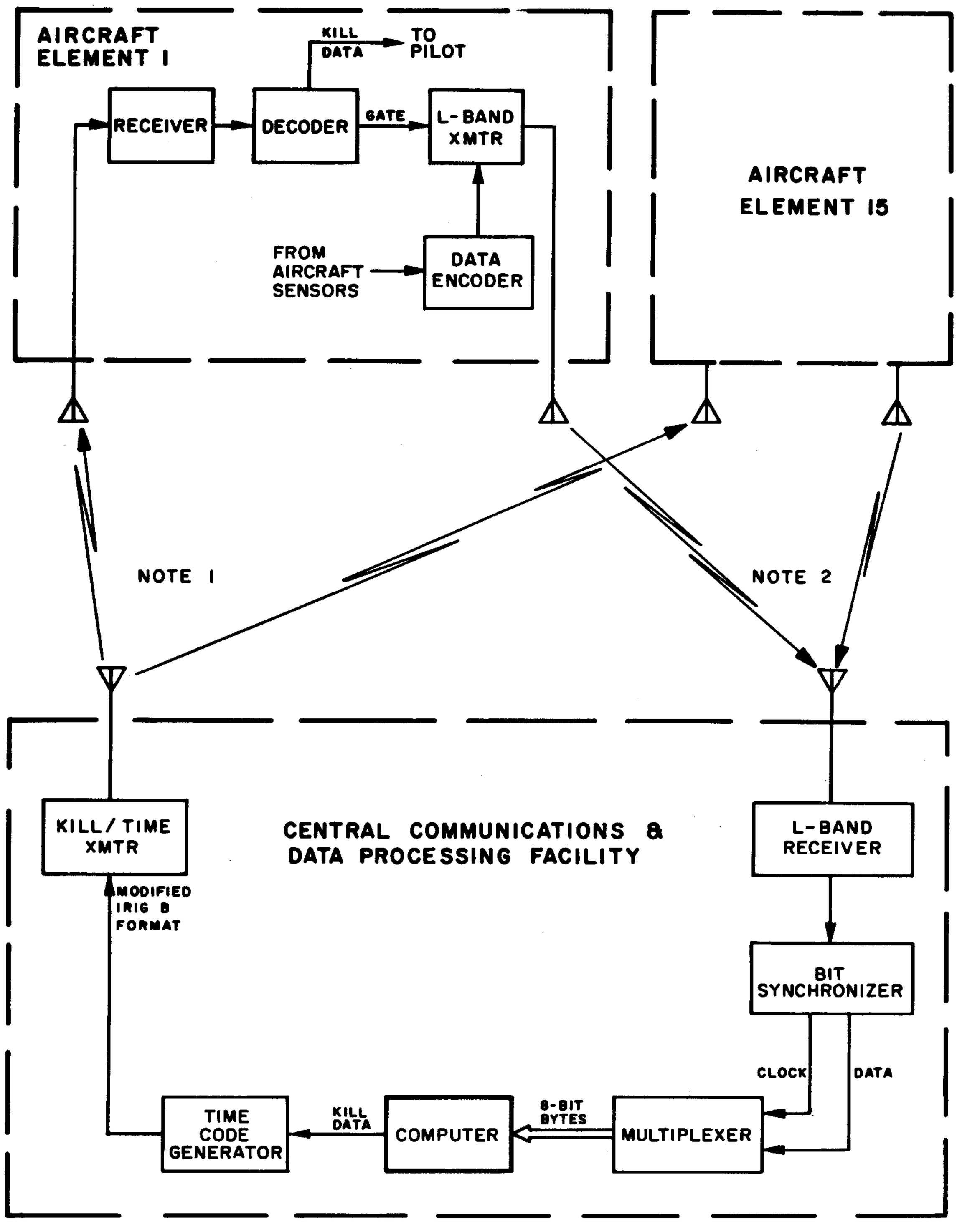


Figure 1. Weapons Evaluation System Concept



NOTES:

1- UPLINK CARRIER FOR KILL/TIME FORMAT IS ON CONTINUOUSLY.

2- DOWNLINK CARRIER FOR DATA IS TIME SHARED.

Figure 2. Aircraft/Facility Equipment, Simplified Block Diagram

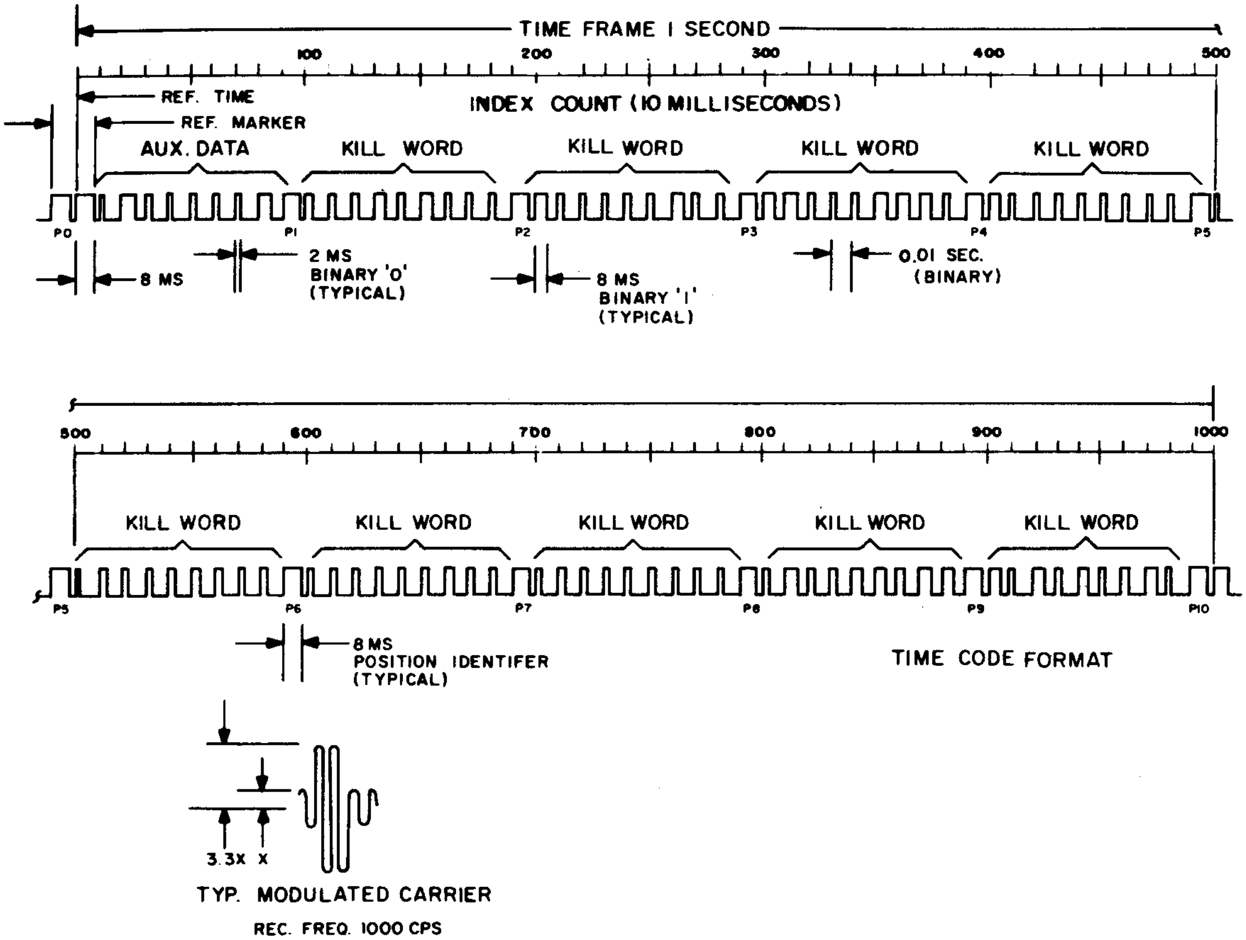


Figure 3. Kill/Time Code Format

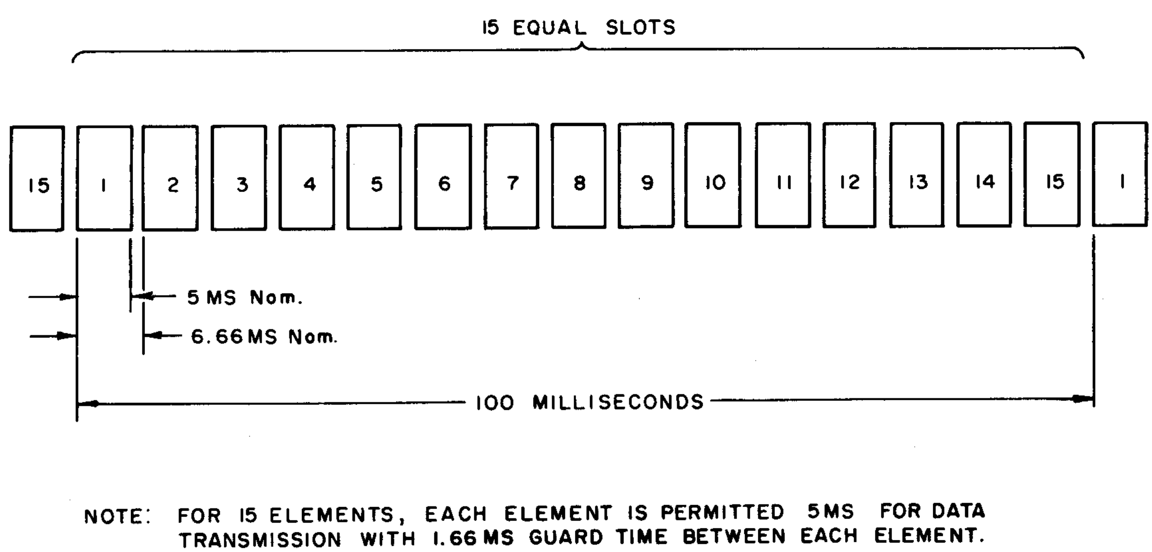


Figure 4. System Time Sharing Plan for Fifteen Elements

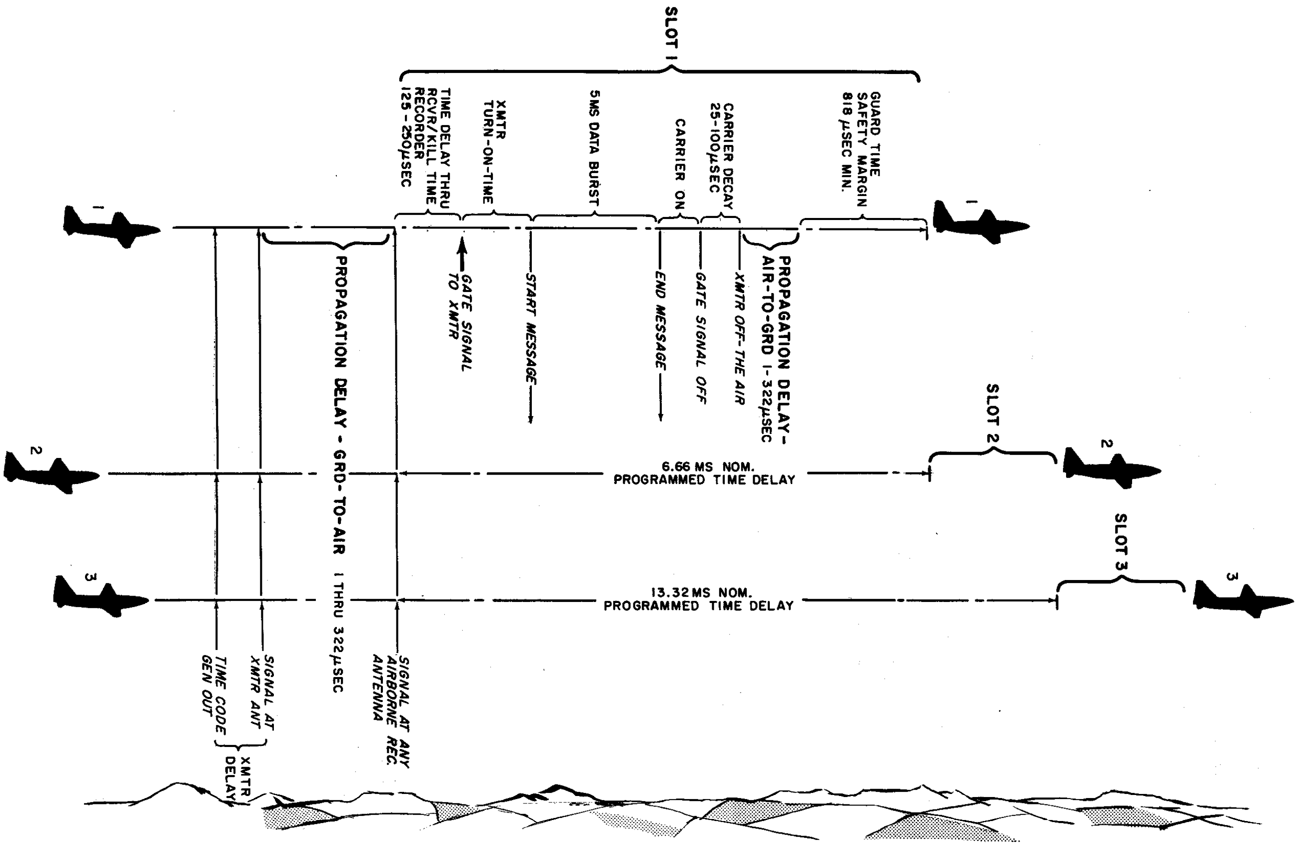


Figure 5. System Data - Flow Time Sequence Chart

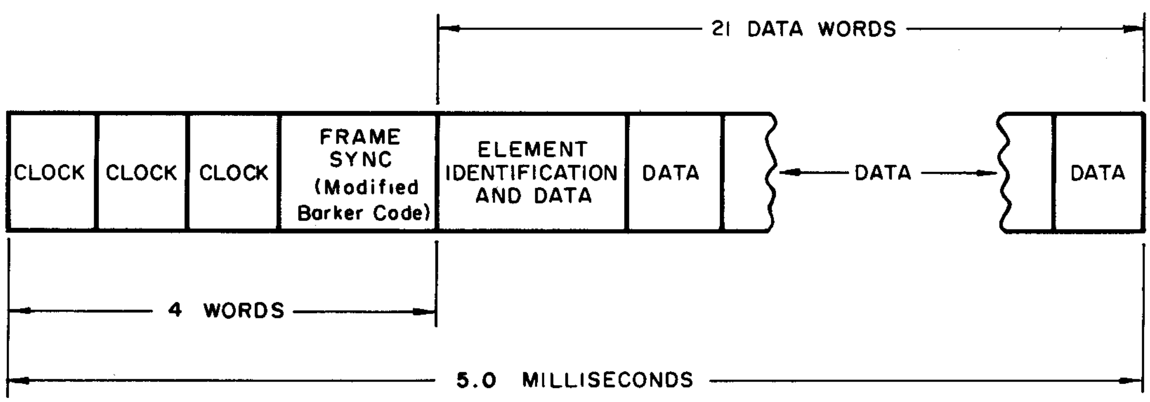
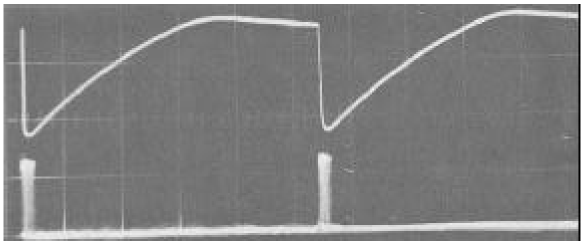
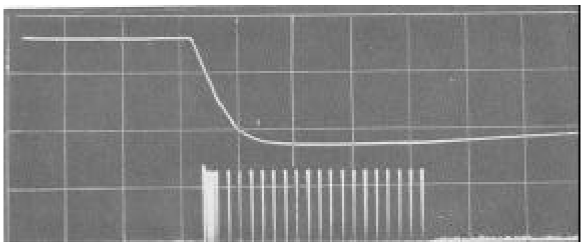


Figure 6. Any Element Data Burst Format



a. A.GC receiver performance curve at a time base of 20 msec/cm

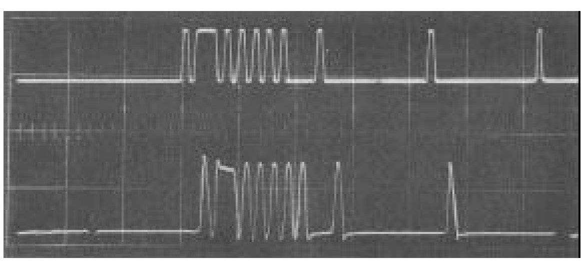
b. Simulated 100-ms data frame output with data in the first 5 msec-slot only. Same time base as above.



c. AGC curve of item a above at a time base of 1 msec/ CM.

d. Data frame of item b at a time base of 1 msec/cm

Figure 7. Receiver Test with AGC



a. Data input to transmitter used in the test at a time base of 0.3 msec/cm

b. Receiver data output for above transmission.

Figure 8. Receiver Test Without AGC

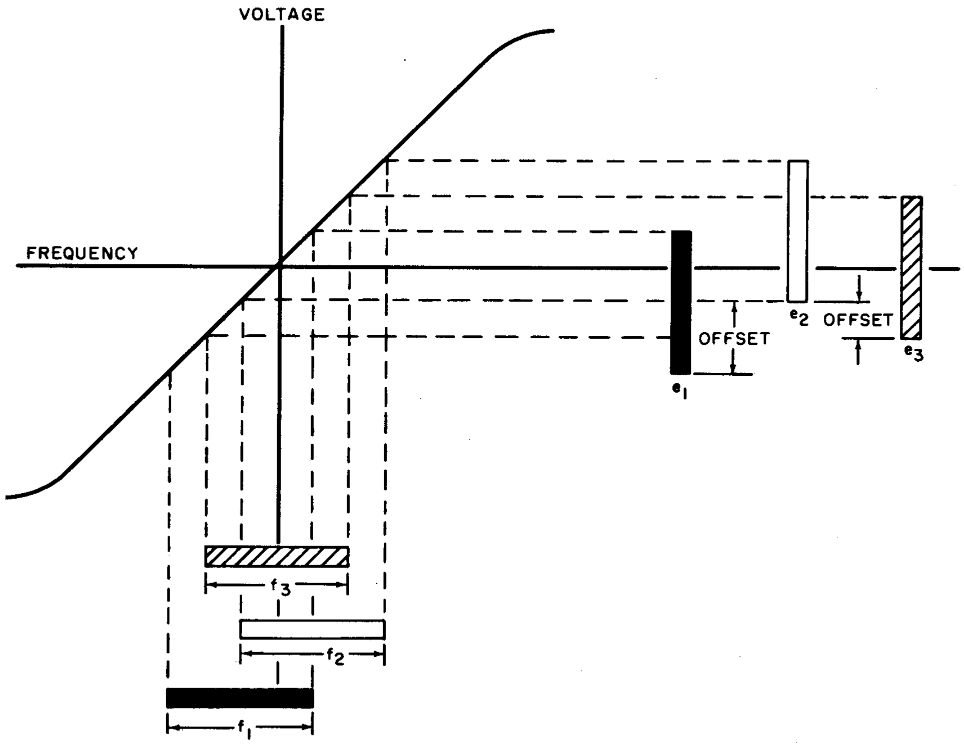


Figure 9. FM Receiver Discriminator Characteristic Curve

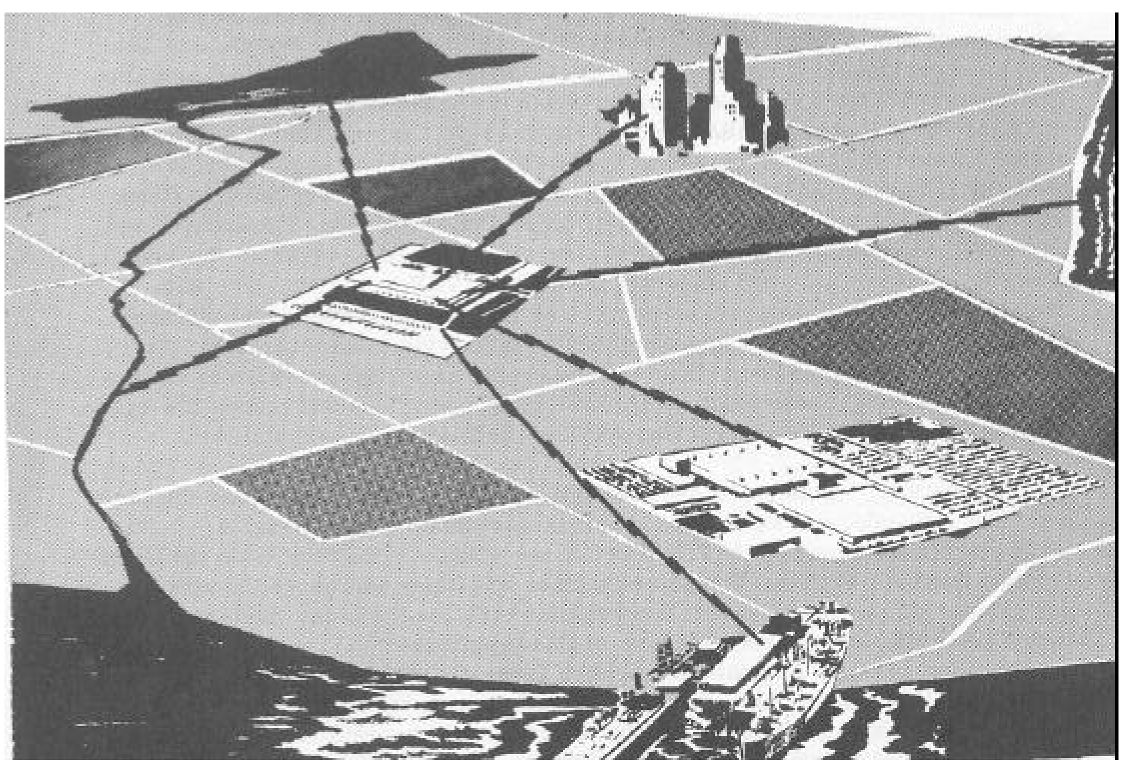


Figure 10. Air/Water Pollution Control System