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Advanced Mobile Phone Service:

A Subscriber Set for the Equipment Test

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The AMPS *mobile telephone subscriber set, which is the mobile customer's link with the switched telephone network, consists of three basic elements: a control unit, a transceiver, and a logic unit. The control unit is the subscriber's primary contact with the* AMPS *system and is mounted in the passenger compartment of the automobile, within easy reach of the driver. The transceiver unit, generally mounted in the trunk compartment of the automobile, is attached to the control unit, logic unit, and antennas with appropriate interconnecting cables. The logic unit functions as a master controller for the mobile telephone equipment. A microprocessor-based design, using software implemented logic, governs the primary supervisory functions and furnishes operating flexibility.*

I. INTRODUCTION

The AMPS mobile telephone subscriber set interfaces the mobile telephone customer with the switched telephone network via a two-way UHF radio path that connects the subscriber's automobile with a cell site. Voice signals, which are frequency-multiplexed with line supervision signals or time-multiplexed with 10-kb/s control signals, flow over this radio path.

The mobile telephone subscriber set consists of three basic elements: a control unit, a transceiver, and a logic unit.

The control unit is the subscriber's primary contact with the AMPS system and is mounted in the passenger compartment of the automobile, within easy reach of the driver and front seat passengers. It serves as the required physical interface between the customer and the telephone network via a handset for acoustical interface, a pushbutton keypad for entering commands into the telephone network, and signal lamps and/or acoustic tones for customer alerting.

The transceiver unit, generally mounted in the trunk compartment of the automobile, is attached to the control unit and antennas with appropriate interconnecting cables. The transceiver is an all-solid state, full duplex, 850-MHz radio. It features 666 channel operation over the 825- to 845-MHz transmit band and the 870- to 890-MHz receive band, with 45-MHz duplex channel spacing. The transmitter provides 12 watts of output power at the antenna port, with phase-modulated audio or frequency-modulated 10 kb/s data. The receiver amplifies and demodulates selected signals from the diversity antennas and supplies voice output to the control unit and data output to the logic unit for decoding.

The logic unit functions as a master control for the mobile telephone equipment. It encodes and decodes 10 kb/s wideband digital information transmitted between the cell site and the mobile unit, performs transceiver control functions, and supplies user alerting information. A microprocessor-based design, using software-implemented logic, governs the required control functions and furnishes operating flexibility.

Two types of transceivers are being produced by outside manufacturers. The first transceiver uses a separate logic unit designed by Bell Laboratories. The second is a single, integrated transceiver/logic unit package.

The stand-alone transceiver with separate logic unit was installed in approximately 100 mobile units for the Equipment Test phase of a developmental system trial in Chicago[1] during mid-1978.

The integrated transceiver/logic unit package will be installed in approximately 2000 mobile units for the Service Test phase of the Chicago trial during 1979.

This paper describes the stand-alone transceiver, separate logic unit, Equipment Test subscriber unit, since only this unit was available at the time of this writing. However, it has essentially the same operating features as the Service Test unit.

II. CONTROL UNIT

A companion paper[2] describes the Service Test mobile control unit as well as general guidelines for design of an AMPS control unit based on human factor considerations. In this section, we consider the design of the Equipment Test control unit, which incorporates some of these guidelines.

Figure 1 is a photograph of the Equipment Test control unit which is composed of two sections: a handset and a cradle assembly interconnected to each other by a coiled plastic-covered cable. On the face-down side of the handset are the usual earphone and microphone.*

* In telephone parlance, the microphone is also known as a "transmitter," and the earphone as a "receiver."

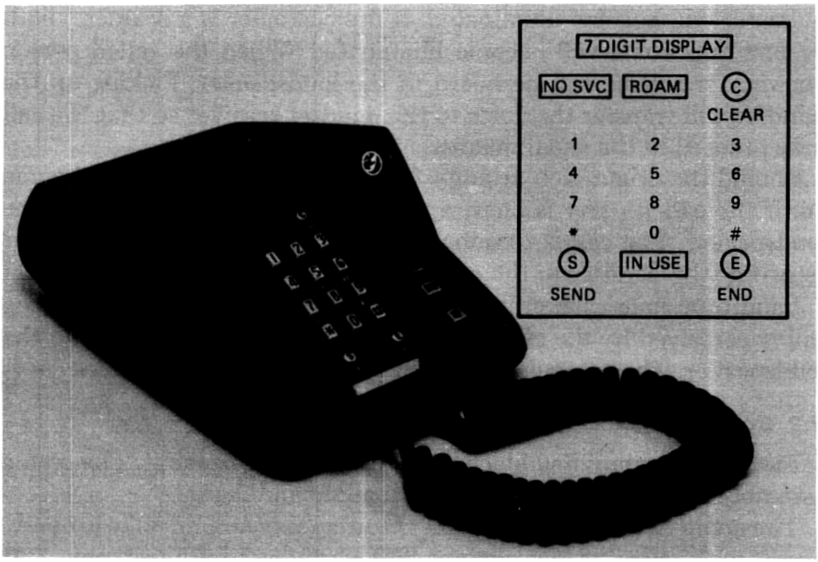

Fig. 1—Equipment test mobile control unit.

The earphone is similar in performance to the land telephone L3 unit, but a dynamic microphone replaces the carbon "transmitter."

The insert on Fig. 1 is a detailed sketch of the back (face-up) side of the handset which contains a dialed digit display, a pushbutton keypad, three call control keys labeled SEND, END, and CLEAR, and three back-illuminated indicator signs labeled NO SVC (no service), ROAM, and IN USE.

The cradle assembly contains a dc power key switch (in the upper right-hand corner), a loudspeaker with volume control, and two push-buttons labeled MW (message waiting) and HF (hands free).

2.1 Control unit operation

To originate a telephone call, the subscriber first turns on the dc power with the keyswitch. The subscriber performs preorigination dialing by depressing, in *TOUCH-TONE*® service fashion, the proper sequence of numbered pushbuttons. The "dialed" number will appear, moving from right to left, upon the 7-digit fluorescent display. If a 10- (or more) digit number is generated, only the last 7 digits will remain upon the display. If the customer makes a mistake, the CLEAR button should be depressed, which blanks the display so that a new origination attempt can be made.

When the customer is satisfied that the correct number has been entered into the display, call origination is started by depressing the SEND button. If the origination task proceeds successfully, the IN USE indicator will become illuminated. If the customer is a roamer,* both IN USE and ROAM will become illuminated. When the called person answers, the voice will be heard in the loudspeaker. Picking up the handset will transfer the voice to the handset receiver so that the call may proceed in the usual manner.

Should the origination attempt fail, the NO SVC indicator will come on. If the called party is busy, a reorder tone will be heard from the loudspeaker. The call is terminated by depressing the END button or returning the handset to the cradle.

Land-to-mobile calls are processed in the usual way. An incoming call is perceived by the customer by an alerting tone coming from the loudspeaker. The customer responds by picking up the handset.

2.2 Control unit block diagram

Figure 2 is a simplified block diagram of the control unit. The cradle assembly contains two circuit boards: audio and digital.

The audio circuit board contains the necessary amplifiers to properly interface the handset microphone and earphone to the transceiver. It also contains the alerting oscillators, speaker amplifier, and associated volume controls.

The digital circuit board provides the digital interface between handset and logic unit.

The handset is connected to the cradle assembly with a 14-conductor handset cable. For this design, no attempt was made to multiplex the control/indicator functions. Thus, the SEND, END, NO SVC, ROAM, and IN USE functions are interconnected with the logic unit on essentially a one-wire-per-function basis.

When a numbered pushbutton is depressed during dialing, the decimal digit is first converted to a 4-bit binary number stored in a 64-bit recirculating shift register in the handset. The "dialed" digits, circulating around the shift register, drive the time-multiplexed, seven-segment, seven-digit fluorescent display. When the user depresses the SEND key to originate a call, the logic unit reads the recirculating shift register serially and stores the digits in the microprocessor random access memory (RAM).

III. TRANSCEIVER UNIT

Figure 3 is a photograph of the Equipment Test transceiver unit, mounted on top of its companion logic unit. Because the mobile transceiver is basically a reversed† cell-site transmitter-receiver, many

* A "roamer" is a mobile customer obtaining service in a foreign (non-home) Mobile Service Area (MSA). Roaming services have been defined in Ref. 3.

† The transmit and receive bands are interchanged (reversed).

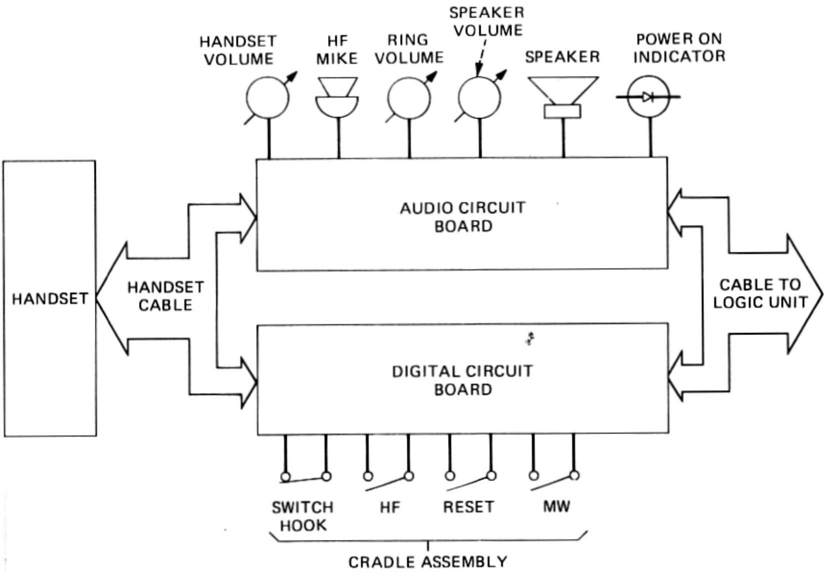

Fig. 2—Block diagram of control unit.

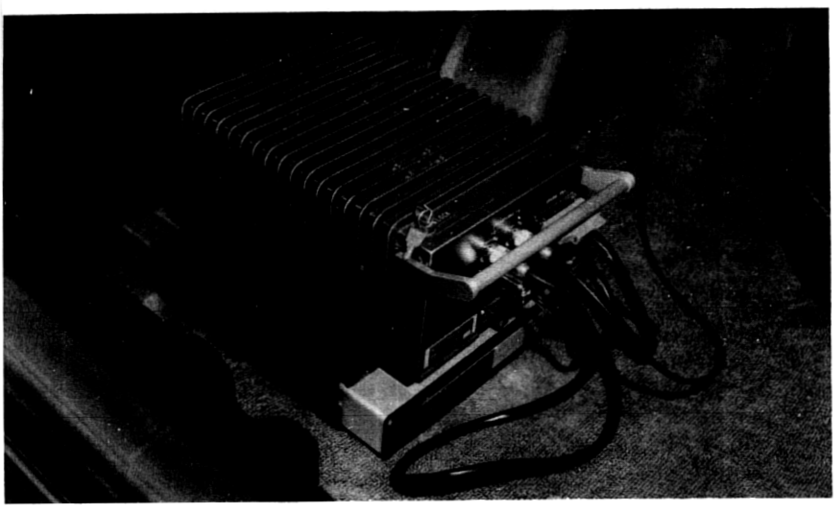

Fig. 3—Transceiver/logic unit.

transceiver subsections share a commonality with the cell-site radio described in Ref. 4. Thus, this section covers in depth only those transceiver subsections that differ substantially from any counterpart within the cell site.

The AMPS transceiver must have capabilities not found in present mobile telephone systems. First, it must, upon command from the cell site, generate any one of several hundred RF channels. This new function requires a sophisticated frequency synthesizer. Second, the mobile unit must use space diversity to protect the RF channel against Rayleigh fading, thus allowing larger cells and closer frequency reuse. Third, new circuit technologies, such as high-level integration, must be used to reduce the mobile cost significantly.

The transceiver unit (see the block diagram in Fig. 4) is a sophisticated FM transmitter-receiver. It supplies duplex voice transmission and reception by dividing the RF band into two segments separated by the 45-MHz IF frequency, so that one frequency-generating system may serve as the source of both transmitter and local oscillator power.

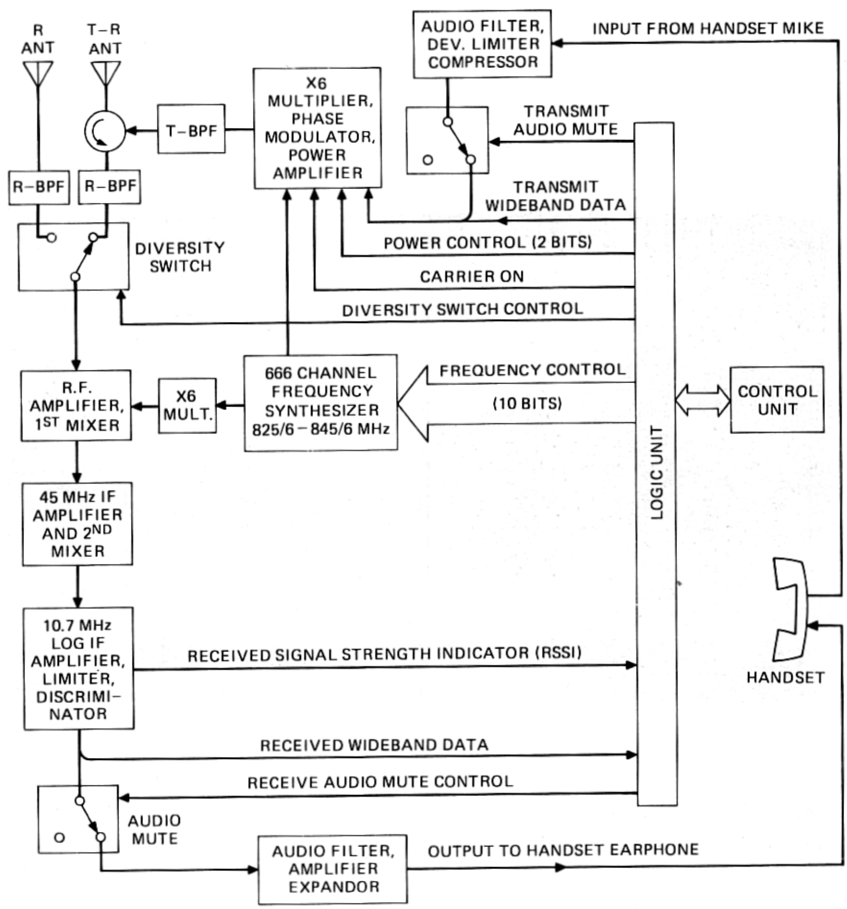

Fig. 4—Mobile transceiver block diagram.

The transceiver unit consists of several basic blocks operating together in the following manner: First, the frequency synthesizer generates any one of the 666 stable carriers upon digital command from the logic unit. Each milliwatt carrier is located in the 140-MHz region, which is ⅙ of the final output frequency. A portion of the synthesizer power output is phase-modulated with audio from the telephone handset or frequency-modulated with wideband data from the logic unit. It is then multiplied in frequency six times and amplified in power to 12 watts by a transistorized modulator-multiplier-amplifier chain. The resulting signal, after being filtered for harmonic and spurious signals by a seven-stage 825- to 845-MHz transmit bandpass filter (T-BPF), is radiated by the vertically polarized transmit-receive (T-R) antenna.

Received signals entering the receive (R) and T-R antennas arrive at two identical seven-section, 870- to 890-MHz receive bandpass filters (R-BPF) that perform two functions: one ensures that the transmitter signal reflected by the T-R antenna (due to imperfect impedance match) will not overload the first mixer; the other protects the mixer from out-of-band signals such as nearby UHF TV transmitters.

The bandpass filter output signals enter the diversity switch, a PIN diode type actuated by a binary switching signal originating in the logic unit. The diversity switch output signal enters the radio frequency (RF) amplifier, then the first mixer where it is combined with a local oscillator (LO) derived from the frequency synthesizer and a low-power (10 mW) "times six" transistor frequency multiplier. Since the transmitter and LO are at the same frequency, the IF frequency is 45.0 MHz, the difference between the transmit and receive frequencies.

The mixer output at 45.0 MHz is amplified by a single-stage IF amplifier, and then down-converted by the second mixer to a second IF frequency of 10.7 MHz. The output is then filtered, limited, and finally demodulated by a frequency discriminator. The resulting audio or wideband data passes to the telephone handset receiver or to the logic unit, respectively.

3.1 Frequency synthesizer

The frequency synthesizer (Figure 5) generates any one of 666 stable carriers upon digital command from 10 parallel binary lines originating in the logic unit. Each milliwatt carrier, located in the 140-MHz region, is stable in frequency to within ±2.5 parts per million over a −40° C to +70° C temperature range.

A relatively unstable voltage controlled oscillator (VCO) generates the output carrier frequency f_0. A portion of the output carrier power enters a mixer where it is heterodyned against the third harmonic of a master crystal oscillator operating at $f_{1/3} = 43.92$ MHz. The difference

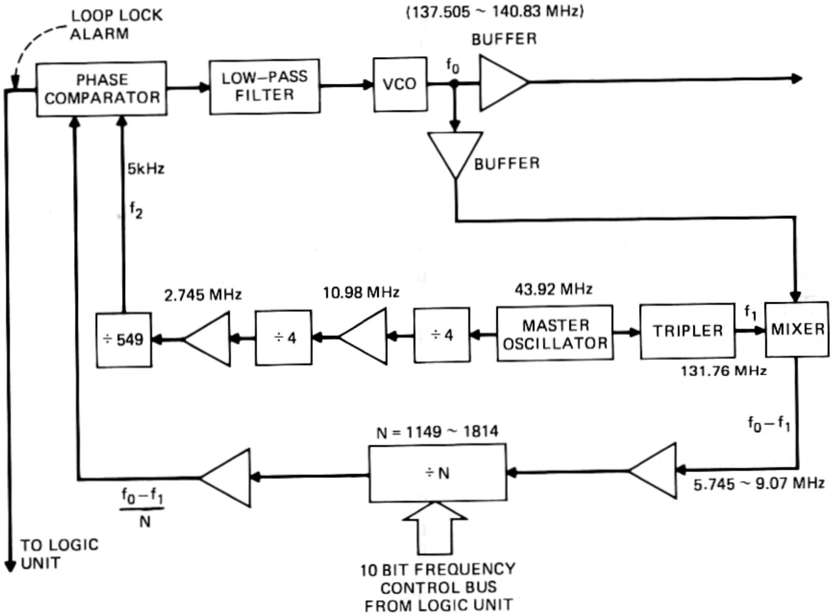

Fig. 5—Frequency synthesizer.

frequency, $f_0 - f_1$, which is in the 5.7- to 9.1-MHz region, is "divided down" by an integer N in a programmable digital frequency divider. The combination of binary dc voltages on the 10 binary program lines determines the division factor N. The divider output frequency, $(f_0 - f_1)/N$ nominally at 5 kHz, is compared with a stable 5.0-kHz reference frequency f_2 in the phase comparator. This reference is obtained by "dividing down" the 43.92-MHz master oscillator by a factor of 8784. Any phase error feeds back to the voltage-controlled oscillator, in the form of a dc control-voltage, thus keeping the total loop in phase lock. When in lock, the output frequency is given by $f_0 = f_1 + Nf_2$; therefore, f_0 will have the same long-term frequency stability as the 43.92-MHz master oscillator and yet can be varied in integer steps by assigning different numerical values to N.

The synthesizer output is quite pure; spurious frequencies are at least 90 dB down from the main carrier, noise that is 45 MHz removed from the carrier does not degrade the mixer noise figure, and phase noise associated with the carrier does not degrade a 30-dB audio output s/n ratio.

3.2 Phase modulator, multiplier, and power amplifier

The phase modulator, multiplier, and power amplifier chain are shown in Fig. 6. The phase modulator is a two-stage reflection type

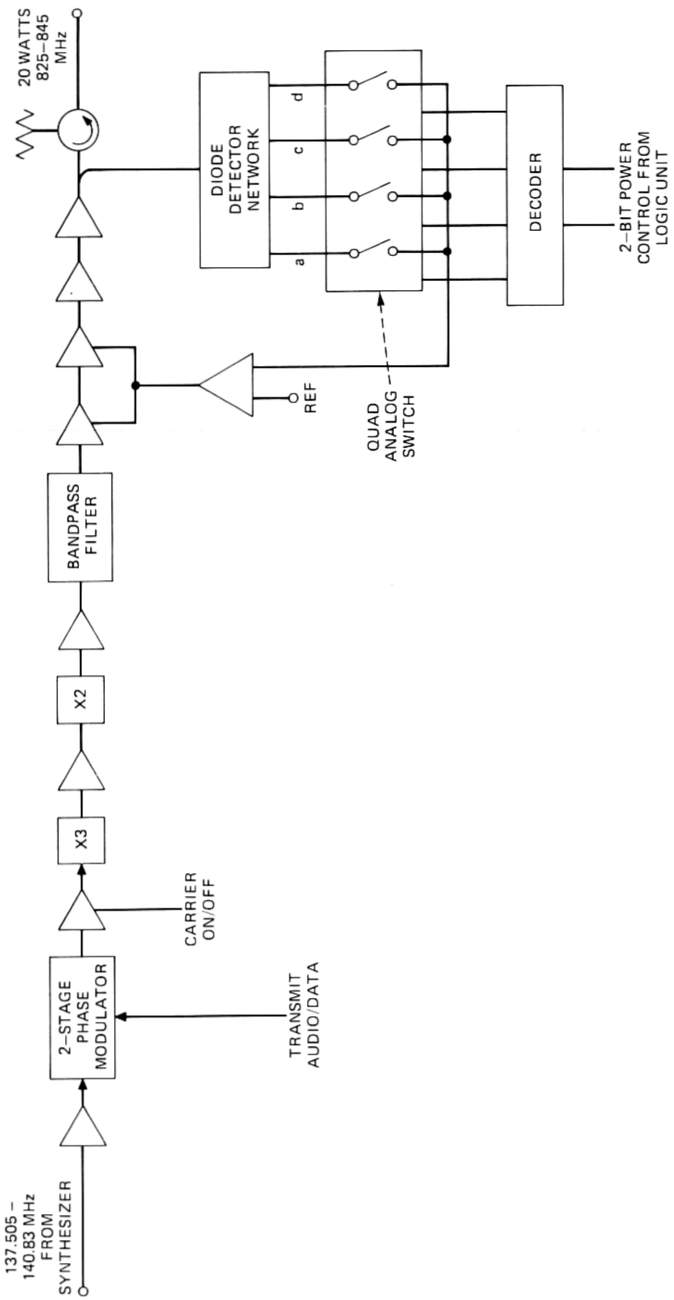

Fig. 6—Phase modulator, multiplier, and power amplifier.

employing varactor diodes driven by lumped element hybrids. The circuit provides a ±2-radian peak phase shift at ⅙ the output frequency. This allows a peak modulation index of ±12 radians after the frequency has been multiplied by a factor of 6 in the subsequent stages. Audio harmonics are at least 25 dB down at the maximum modulation index.

The multipliers and power amplifiers are all bipolar transistor Class-C amplifiers. Frequency multiplication is obtained, first by a factor of 3 and next by a factor of 2, by the classic method of tuning the collector stage of a transistor amplifier to the second or third harmonic of its input frequency.

Subsequent "straight-through" class-C amplifiers build up the milliwatt signals from the multipliers to about 20 watts output.

Power control is achieved by first detecting a sample of the output power by the diode detector network which has four different dc output voltages labeled *a*, *b*, *c*, and *d*. One of these four dc voltages is selected by the quad analog switch and delivered to a dc amplifier, which provides collector bias to two stages of the RF power amplifier. Thus, a servo network is formed that tightly regulates the RF power at one specified level. Should a different output level be desired, a new detector output voltage would be chosen by the analog switch which is driven by the 2-bit power control bus through a decoder. Thus, we obtain stable output power levels of 0, −6, −12, and −18 dB with respect to 12 watts (at the T-R antenna) by digital signals arriving from the logic unit.

A post transmitter bandpass filter (T-BPF in Fig. 4) reduces out-of-band noise and spurious signals to a level more than 55 dB below the 12-watt carrier. Noise at the receive channel, 45 MHz higher, is below −120 dBm. The output power does not vary more than ±1 dB over the supply battery voltage range of 11 to 16 volts. The transmitter is designed to operate reliably and provide long life over a −40° C to +70° C temperature range.

3.3 Receiver chain

The receiver chain (see Fig. 7) follows the 870- to 890-MHz bandpass filter, and includes a two-stage RF amplifier, a first mixer, a 45-MHz IF amplifier, a second mixer, a filter, a limiter, and a discriminator. The receiver chain, like other portions of the mobile unit not subject to complete monolithic integration, achieves performance objectives at minimum cost.

The first unit in the receiver is a two-stage RF amplifier providing 15-dB gain with about a 3-dB noise figure. The composite receiver noise figure, measured at either of the two antenna ports, is about 6 dB.

Signals from the RF amplifier enter the first mixer where they are heterodyned against the 825- to 845-MHz local oscillator and converted

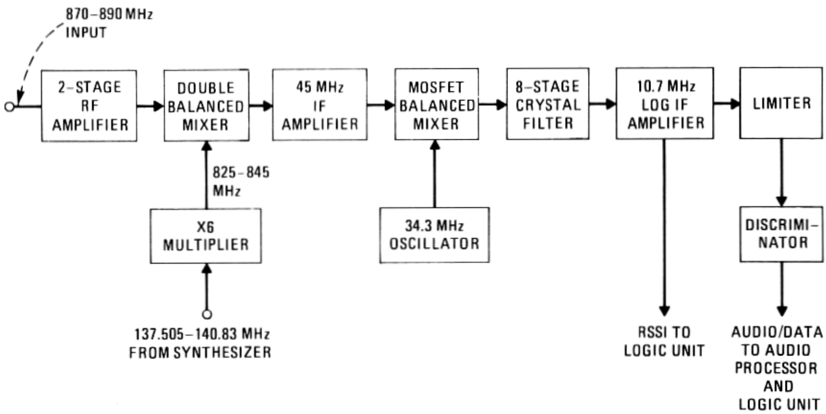

Fig. 7—Receiver.

to the 45.0-MHz first IF frequency. The mixer uses Schottky barrier diodes in a double balanced configuration. The conversion loss is about 6 dB.

The first IF amplifier employs a single common-source junction field-effect transistor (FET) yielding a gain of about 10 dB. Since the bandwidth of this stage is about 100 kHz, there is little channel filtering here. The second mixer consists of a single-balanced circuit built around two metal oxide semiconductor (MOS) FETs. Since essentially no channel filtering has yet been accomplished, this second mixer must be exceptionally resistant to the unwanted generation of cross modulation and intermodulation products.

A 34.3-MHz crystal-controlled oscillator provides injection to this second mixer. The resulting 10.7-MHz second IF signal then passes through an eight-resonator quartz crystal bandpass filter for the required channel filtering. This filter exhibits a 6-dB bandwidth of 28 kHz and 60 dB rejection of signals 60 kHz from the center of the passband.

The log IF amplifier[5,6] consists of a cascade of progressively saturating differential amplifiers. Diode detectors are stationed at the output of each amplifier stage. The output currents from these detectors are summed in a network providing a log-amplifier output voltage called the received signal strength indicator (RSSI). This RSSI voltage rises smoothly and monotonically over an input signal range of −110 to −30 dBm measured at the antenna. The RSSI provides important signal strength information to the logic unit and switched diversity circuits. The limiter is designed to assure "hard" limiting over a dynamic range of at least 80 dB.

The subsequent discriminator operates at 10.7 MHz and has a "peak-to-peak" spacing of about 50 kHz. It consists of a quadrature detector and a narrowband delay network primarily composed of a 10.7-MHz quartz crystal. Harmonic distortion is more than 32 dB below a reference 1000-Hz tone with ±8-kHz peak deviation.

3.4 Switched diversity

In a conventional nondiversity radio system, a single modulated RF carrier is propagated through space to the mobile receiver, where it is detected, amplified, and demodulated. For the two-branch diversity radio system described here, the RF carrier is fed to a single, vertically polarized, land-based antenna after modulation. This signal is then received by two vertically polarized antennas, separated by an appropriate distance, at the mobile receiver. If the antenna separation is sufficient (a few quarter-wavelengths), the two received signals are highly decorrelated; if one signal is in a deep fade, the other signal may be quite strong. The statistics of these Rayleigh fading signals have been thoroughly discussed by Jakes.[7]

A diversity receiving system can be quite expensive if it has multiple receivers. A method that employs a single receiver[8] and yields low-cost diversity is shown in Fig. 8. Here, a conventional single-channel FM receiver connects to two antennas, R and T-R, via a single-pole, double-throw semiconductor diode switch. The switch commands, generated by a hard-wired logic controller, attempt to keep the receiver RF input always connected to that antenna with the stronger signal.

3.5 Detailed circuit operation

The specific switching algorithm used in the circuit was devised by Shortall.[9] The function of the logic circuit is to generate a switch command whenever the instantaneous received carrier amplitude drops approximately 10 dB below its mean. As noted in Section 3.3, the log IF amplifier produces a dc voltage (RSSI) proportional to the log of the instantaneous carrier envelope.

Consider Fig. 8: The envelope output from the log IF (15) feeds through the highpass filter (1) that removes the dc component (i.e., the mean carrier amplitude) and allows only the fading information to pass. The filter cutoff frequency was chosen to be 0.5 Hz, which is high enough to block the slow variations in mean signal strength that occur when the vehicle is moving. The fading signal passes through a 2-kHz low-pass filter (2) to remove any high-frequency noise not related to fading. This filtered signal, with zero mean, is compared (see sketch A) with a negative dc reference corresponding to a 10-dB drop in signal power, in a comparator (3). If the signal drops below this reference, the comparator goes high and turns on a gated astable multivibrator (5), which generates switching pulses at a 2-kHz rate. At 35 mph, the average fade duration at the 10-dB level is 1 ms. The astable multivibrator switching pulses pass through the OR gate (6) and actuate the

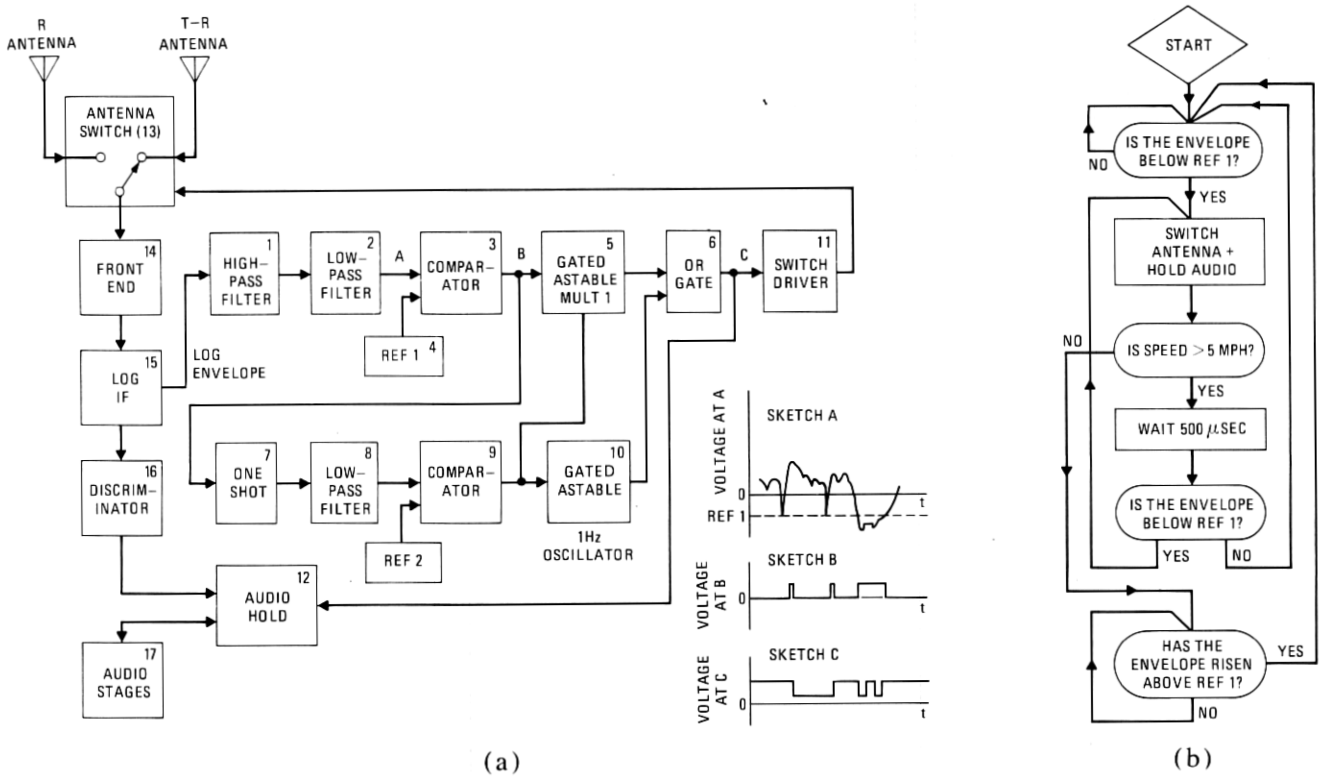

Fig. 8—Block diagram of switched diversity system and logic flow chart.

antenna switch (13) and the audio hold (12). When the signal falls below threshold, the first pulse from the astable multivibrator (5) causes a switch to the other antenna. If the signal is higher there, the comparator (3) turns the astable multivibrator (5) off before it can deliver another switch pulse. If the signal is lower at the other antenna, the astable multivibrator (5) continues to generate switch pulses until the signal at one of the antennas rises above threshold. If both of the signals should suddenly disappear, the circuit hunts for about 2 seconds, while the mean signal level stored in (1) goes to zero, and then stops.

Circuits 7 through 9 serve to count the number of fades produced over the last several seconds. Whenever the comparator (3) goes high, the one-shot multivibrator (7) delivers a pulse to the low-pass filter (8). The dc output of filter (8) is therefore proportional to the fade rate. It is compared in (9) with a reference adjusted so that the output is high whenever the fade rate is greater than 5 Hz, which corresponds to a vehicle speed of about 5 mph. When the vehicle speed falls below 5 mph, the comparator (9) is low, and the operation of unit (5) is changed from a gated astable multivibrator into a one-shot multivibrator. This change prevents the circuit from "hunting" during the long fades encountered when the vehicle is moving slowly.

Gated astable (10) is also turned on at low fading rates. It generates switch commands at a slow (1-Hz) rate to keep the receiver on the better antenna. Assume that the receiver is connected to antenna 1, and that the signal at antenna 2 is much weaker. The signal will drop suddenly when a switch is commanded by unit (10); but units (1), (2), (3), and (5) will interpret this as a fade and immediately bring the receiver back to the original antenna. Now, assume the receiver is connected to antenna 2 and that the signal at antenna 1 is much higher. The signal rises suddenly when the switch is made, and the mean signal strength stored in unit (1) rises as well. The next switching pulse causes the signal level to drop below the mean and, if the two signals differ by 10 dB, circuits (1), (2), (3), and (5) interpret this as a fade and switch back to antenna 1. Therefore, if the signal levels at the two antennas differ by more than 10 dB, the receiver is always connected to the better antenna. A logic flow chart for the system is shown in the lower part of Fig. 8.

The audio hold circuit is necessary to suppress audible switching transients produced by the sudden change in signal amplitude and phase during the antenna changeover which sets up ringing in the bandpass filters of the IF amplifier.

IV. LOGIC UNIT

The decision to use an outboard, Bell Laboratories-designed logic unit with the equipment test transceivers was made for two reasons.

First, contemporary radio manufacturers could readily supply a transceiver without logic. Thus, a contract for only the transceivers could be let well in advance of the equipment test without much risk. Second, the final decisions about the AMPS logic and control algorithms were made rather late in the development schedule. Thus, it was felt that the approach with the lowest risk was for Bell Laboratories to develop a logic unit which, if required, could be modified expeditiously.

Subsequent mobile units will have integrated transceiver/logic units with the logic unit designed by the radio manufacturer.

4.1 Logic unit sections

A mobile telephone logic unit can be conveniently divided into two sections: the digital section and the analog section.

The analog section performs analog (or quasi-analog) tasks such as:

(*i*) 10-kb/s data reception and clock regeneration.

(*ii*) Supervisory Audio Tone (SAT) detection, reconstitution, and transponding.

(*iii*) Conversion of the analog received signal strength indicator signal into a binary number via an A/D converter.

The digital section performs all necessary logic operations required for AMPS call processing. The immense complexity of these call-processing functions has made the use of a stored-program controller all but mandatory. Thus, an 8-bit microprocessor was chosen to perform this task.

4.2 Digital section

4.2.1 Microprocessor

Figure 9 is a functional block diagram of the Bell Laboratories-designed logic unit. Its nucleus (1) consists of an INTEL 8080 one-chip microprocessor. This is an 8-bit parallel central processing unit (CPU) driven by a 2-MHz, two-phase clock (2).

The microprocessor has a 16-bit* address bus and an 8-bit bidirectional data bus, which it uses on a time-shared basis to communicate with memories and input/output (I/O) circuits. The microprocessor also provides periodically an eight-bit status word which is used by the CPU system controller (2) to develop signals for all the peripheral circuits.

The CPU has an interrupt control line which is held at logic 0 for normal program flow. A peripheral device can at any time request service from the CPU by simply applying a logic 1 on this control line, whereupon the CPU interrupts the main programs, sends an acknowledgment to the requesting peripheral, and executes instructions "jammed in" externally by the latter.

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* Only 13 bits are used.

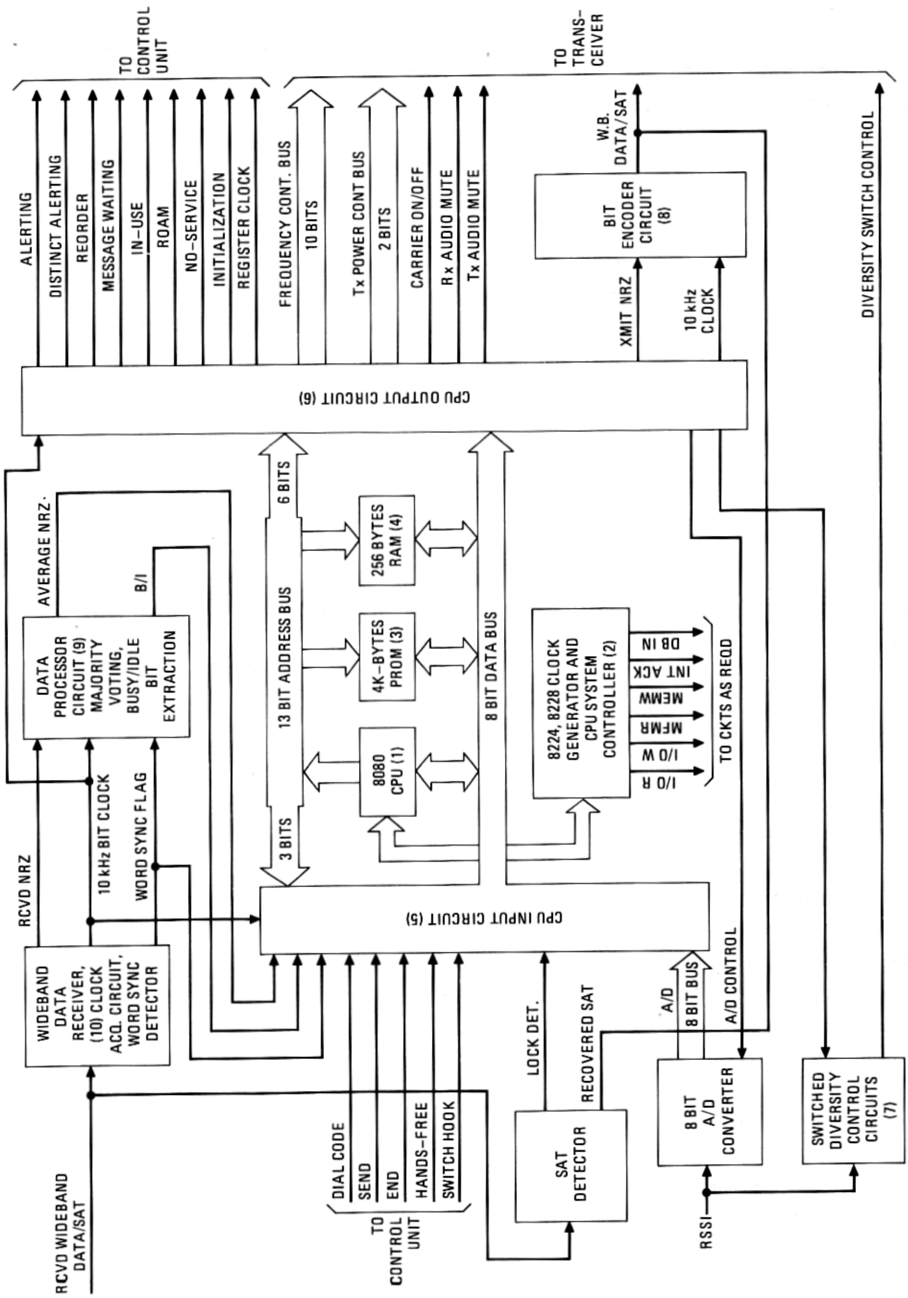

Fig. 9—Functional block diagram of Bell Laboratories-designed mobile logic unit.

The total memory is contained within a 4K-byte programmable read-only memory (PROM) (four 1K-byte ultraviolet erasable INTEL 2708s) (3) for main program storage and a 256-byte random access memory (RAM) (two 256 × 4 bit INTEL 5101s) (4) for temporary storage. Also, the NAM (number assignment module) is contained within the PROM.

The I/O circuitry (5) and (6) is the primary link through which external circuits interact with the CPU. The I/O circuits consist principally of an array of latches which store input stimuli or output commands directed to or from the CPU. When a specific latch must be accessed by the CPU, its address appears on the 13-bit address bus, and then an 8-bit data byte is directed to (or from) the addressed latch. Thus, all external peripherals are time-shared by the CPU.

4.2.2 Additional digital circuits

Several digital functions are performed by hard-wired logic circuits which are external to the CPU. Off-CPU logic is sometimes necessary because of speed/time constraints or programming complexity. Second-generation logic units are expected to perform most of the logic functions using software. These functions include (see Fig. 9):

(*i*) The switched-diversity control circuits (7) already described in Section 3.4 and Fig. 8.

(*ii*) The bit encoder circuit (8) which converts the NRZ* data originating in (6) into the Manchester-encoded 10-kbs wideband (WB) transmitted data stream.

(*iii*) The data processor circuits (9) which perform the 3-out-of-5 majority voting and busy/idle bit extraction of the received 10-kb/s data stream.

4.3 Analog section and wideband data receiver

The basic function of the analog circuits in the logic unit is to convert noisy analog signals arriving from the receiver discriminator into clean, clocked TTL binary signals for the CPU. The WB data receiver, block (10) on Fig. 9, is required to perform the following functions:

(*i*) It must distinguish when WB data are present on the discriminator output line, as opposed to the normal voice/SAT signal, to accomplish voice-channel data transmissions. The WB data receiver handles this function with a 5-kHz tone detector (a 5-kHz bandpass filter followed by a diode detector) since a dotting sequence (101010···), with a strong 5-kHz Fourier component, precedes every blank and burst message.

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* Nonreturn to zero.

(*ii*) It must reconstitute a relatively clean 10-kHz bit clock from the noisy WB data signal.

(*iii*) It must, by a minimum error algorithm, convert the noisy received 20k-baud Manchester code into a 10-kb/s NRZ bit stream.

(*iv*) It must detect Barker (word) sync pulses by a constant search for the 11-bit Barker word (11100010010).

We can best describe the implementation of functions (*ii*) and (*iii*) above by briefly reviewing the AMPS wideband data transmission and reception systems. The circuits have been described by Addeo.[10-13]

Figure 10 [a detailed drawing of block (8), Fig. 9] shows the wideband data transmission system and associated waveforms. The NRZ data sequence (A) is exclusive ORed* with the phase-coherent 10-kHz clock (B) to produce the Manchester (biphase) encoded bit stream (C). The clock phase is chosen so that an NRZ binary one becomes a zero-to-one transition in the middle of each NRZ bit cell. Correspondingly, an NRZ binary zero becomes a one-to-zero transition.

Some salient features of Manchester coding are discussed in Ref. 14. The advantages of the Manchester code can be summarized as:

(*i*) The power spectrum (for a random code sequence) peaks at 10 kHz, well above the voice-band. Thus, a data receiver bridged across the FM receiver discriminator can easily distinguish between voice and data transmissions. This facilitates the use of blank and burst techniques so that a voice message is interrupted (blanked) for 200 ms to allow the reception of a data message burst.

(*ii*) The ever-present code transitions, with zero dc component, permit binary FM to be achieved with a voice phase modulator preceded by an integrator.

In Fig. 10, the Manchester-encoded data (C) represent the instantaneous frequency of the desired binary FM waveform, where a binary one represents $f_0 + \Delta f$, and a binary zero represents $f_0 - \Delta f$

f_0 = carrier frequency (in the 825- to 845-MHz band). $\Delta f = 8$ kHz.

If a direct FM deviator were available,† it would be driven by waveform (C). Instead, the mobile transmitter described in Section III employs a phase modulator.

Since

$$\Delta f = \frac{1}{2\pi}\frac{d\theta}{dt},$$

where θ is the carrier phase, the Manchester waveform must be

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* A ⊕ B.

† At the present time, most equipment manufacturers prefer to use a phase modulator instead of a direct frequency deviator.

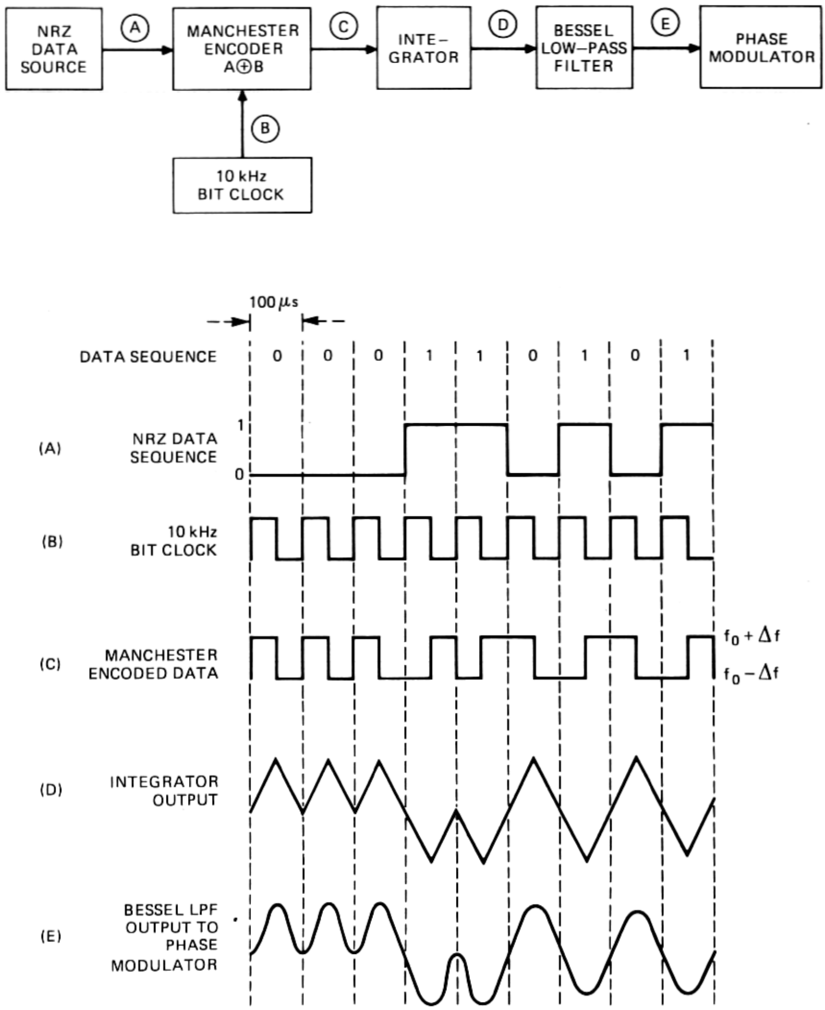

Fig. 10—Manchester bit encoder.

integrated before allowing it to drive the phase modulator. The integrator output is a triangular waveform (D), which is filtered by the Bessel (maximally linear phase) low-pass filter to become the phase modulator drive waveform (E).

Figure 11 (a partial drawing of block 10, Fig. 9) shows the wideband data reception system. Data from the FM receiver discriminator are sliced to become the noisy Manchester bit stream (A). The slicer removes amplitude noise, but the phase fluctuations remain. Thus, (A) is a noisy replica of the transmitted bit stream—waveform (C) of Fig. 10.

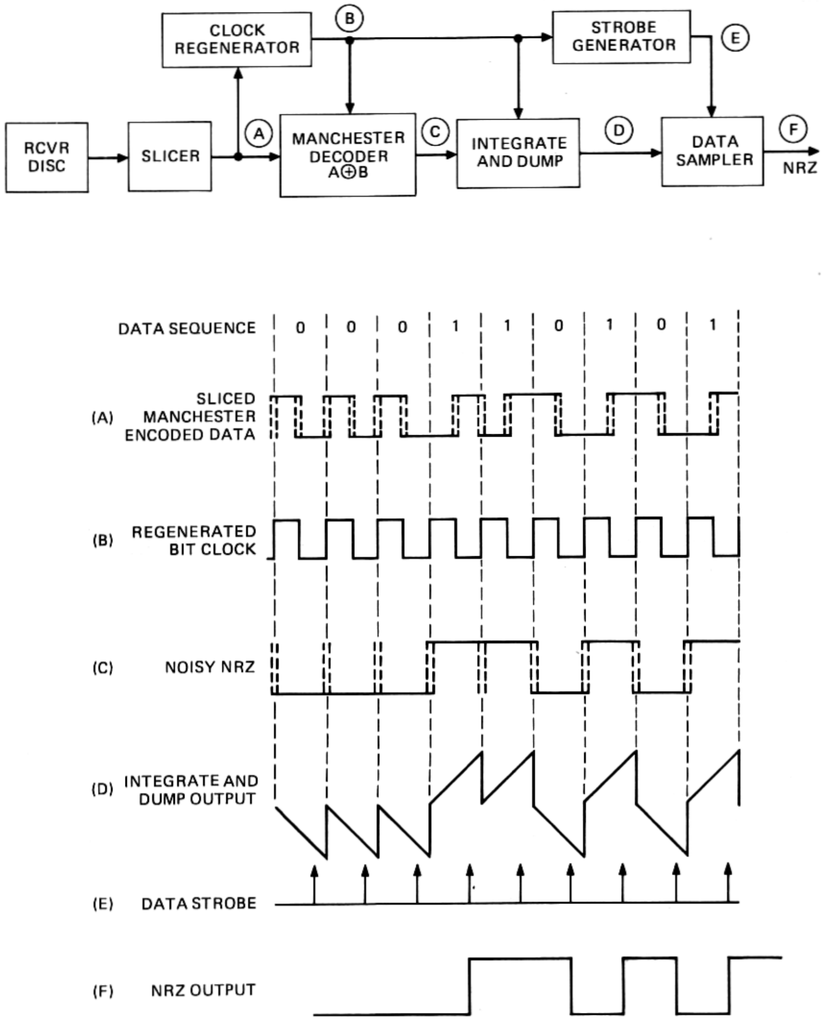

Fig. 11—Wideband data receiver.

A clock regenerator circuit extracts an almost noiseless 10-kHz phase-coherent, clock waveform (B). The regenerator employs a narrowband (10-Hz bandwith) phase-locked loop to extract the 5-kHz Fourier component of the Manchester bit stream. This waveform is then frequency-doubled to obtain the desired 10-kHz bit clock. Certain code sequences—e.g., all ones or all zeros—lack this 5-kHz Fourier component. Thus, the bit clock must be able to "coast through" these sequences.

The Manchester data (A) are then "exclusive ORed" with the bit clock (B) to produce the noisy NRZ bit stream (C). Note that the phase noise on (A) and/or phase error of the bit clock (B) produce unwanted spikes at the borders of each NRZ bit cell. The noisy NRZ bit stream enters the integrate-and-dump circuit, producing waveform (D), which is strobed before each dump by the data strobe (E). The data sampler retains the output from each strobed sample to produce the clean NRZ output (F). The integrate-and-dump circuit can be shown to be a matched filter, thus providing the best signal-to-noise enhancement.

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REFERENCES

1. D. L. Huff, "AMPS: The Developmental System," B.S.T.J., this issue, 249–269.
2. J. T. Walker, "AMPS: The Service Test Mobile Telephone Control Unit," B.S.T.J., this issue, pp. 145–152.
3. W. R. Young, "AMPS: Introduction, Background, and Objectives," B.S.T.J., this issue, pp. 1–14.
4. N. Ehrlich, R. E. Fisher, and T. K. Wingard, "AMPS: Cell-Site Hardware," B.S.T.J., this issue, pp. 153–199.
5. T. H. Chambers and I. H. Page, "The High-Accuracy Logarithmic Receiver," Proc. IRE, August 1954, pp. 1307, 1317.
6. A Woroncow and J. Croney, "A True IF Logarithmic Amplifier with Two-Gain Stages," Radio and Electronic Engineer, September 1966.
7. W. C. Jakes, Jr., *Microwave Mobile Communications,* New York: John Wiley, 1974.
8. A. J. Rustako, Y. S. Yeh, and R. R. Murray, "Performance of Feedback and Switch Space Diversity 900 MHz Mobile Radio Systems with Rayleigh Fading," IEEE Trans. Commun., *COH-21,* No. 11 (November 1973), pp. 1257–1268.
9. W. E. Shortall, "A Switched Diversity Receiving System for Mobile Radio," IEEE Trans. Commun., *COH-21,* No. 11 (November 1973).
10. E. J. Addeo, "Word Synchronization and Digital Signal Processing for a High Capacity Mobile Telecommunication System," 27th Annual Conference of the IEEE Vehicular Technology Group, March 16–18, 1977, Orlando, Fla., pp. 104–106.
11. E. J. Addeo, "An Approach to Digital Signal Processing for a High Capacity Mobile Telephone System," 26th Annual Conference of the IEEE Vehicular Technology Group, March 1976, pp 52–57.
12. E. J. Addeo, "Digital Synchronizing Signal Recovery Circuits for a Data Receiver," U.S. Patent No. 4,029,900, June 14, 1977.
13. E. J. Addeo, "Method and Apparatus for Radio System Co-Channel Interference Suppression," U.S. Patent No. 4,025,853, May 24, 1977.
14. G. A. Arredondo, J. C. Feggeler, and J. I. Smith, "AMPS: Voice and Data Transmission," B.S.T.J., this issue, pp. 97–122.