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system description

Information Science Center | Collins Radio Company, Newport Beach, California

Collins Adaptive Kineplex® Data Communication Modems

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introduction

The Collins series modems (TE-216, TE-217 and TE-218) will provide reliable transmission of digital data over communications facilities with nominal channel bandwidth of 3 kc, 48 kc, and 240 kc. The objective is to provide high data transmission rates per unit of channel bandwidth with suitable tolerance to communications channel characteristics to insure efficient and reliable service.

A further objective is a generalized modem design which is applicable to all data speed applications over different bandwidth facilities and operating frequency ranges. The modem design and physical configuration remains the same and only circuit card substitutions are made to provide for different speed and frequency requirements.

The modems defined herein exemplify the application of this design objective. The TE-216, TE-217 and TE-218 have identical mechanical configuration and will be constructed with a common family of circuits that differ only with regard to frequency dependent elements.

The Collins modems, as specified herein, are intended to operate over communications channels provided by the common carriers. Channel characteristics important to data transmission are amplitude variation and differential delay of the passband, frequency translation, noise and short term net loss. Of these, amplitude variation, differential delay and frequency translation are typically the characteristics that limit the efficiency of data transmission over common carrier channels.

Modem design parameters which define the modem operating tolerance to line characteristics are number of data tones, the transmitted pulse length, and coding of the binary information on each pulse. The relation of data rate to tolerance to line characteristics bears a significant relationship to the number of data tones.

For common carrier facilities, the normalized delay tolerance required is typically a factor of 2 to 3. The transmission efficiency of the modem with binary coding (PSK quadrature) for a constant delay tolerance is greatly improved by increasing the number of data tones. Up to a 20-tone configuration can be defined for the TE-216, TE-217 and TE-218 modems. The modem tone assignments and nominal data rates have been selected to give a normalized delay tolerance of approximately 2.5, yielding a net of 1.4 bits per cycle of bandwidth for straight binary coding.

The characteristics of the common carrier communication channel is that noise to be contended with is impulsive and periodic. The TE-216, TE-217, TE-218 modems employ quadrature PSK modulation (2 bits per pulse) and a single level of AM modulation to encode an additional bit per pulse. This results in a 50% transmission rate increase.

The importance of varying the tolerances of the modem to line characteristics for optimum data rate is apparent. This capability has been incorporated in the design objectives of the TE-216, TE-217, TE-218. The transmitted pulse length can be increased over a range of 2 to 1 while maintaining a constant integration sample time at the detector. The delay tolerance, as a result, is increased as an inverse function of data rate. The choice of a plug-in time base oscillator is used to change the transmitted pulse length and control the delay tolerance data rate trade off.

Reduction in the number of active tones under program control is an option provided by means of a separate on/off remotable control to each data tone modulator. Adverse amplitude delay characteristics on the edge of the passband that may occur can be accommodated at reduced data rate without disruption of service.

The "adaptive" capability for selection of number of tones and pulse length provides the flexibility of maintaining the most efficient data rate compatible with line characteristics.

The following sections 1, 5, 6 specify three modems, the TE-216 for voice bandwidth facility, the TE-217 and the TE-218 for 48 kc and 240 kc bandwidth facilities, respectively. The modems are identical except for frequency and data rate assignments.

section 1

general description

The Collins TE-216 Data Communication Modems consists of equipment designed primarily for use over voice bandwidth derived (3 kc) transmission facilities.

The general characteristics of the TE-216 modems are as follows:

Modulation Used—Synchronous PSK for 2 channels/tone and AM for 3rd channel.

Data Rate—75 bits/second minimum to 6200 bits/second maximum.

Bandwidth Required—2400 cps (3 db points 500-2900 cps).

Guard Time (delay, multipath and sync tolerance)—Can be matched to the media characteristics. Typical values between 30% to 50% of pulse length.

Number of Tones—One tone to twenty tones maximum.

Pulse Synchronization Technique—Outband keyed filter. No special modulation required. Synchronization information derived from composite data tone signal.

Detection Used—Matched filters employing Kineplex® techniques; keyed crystal resonators or R-C correlators available.

Error Rate—Typically 1×10^{-5} or better depending upon media characteristics.

Adaptive Control—The number of channels per tone can be remotely selected. The data tones also can be selectively switched on or off.

Standard modems provide reliable service at data rates up to 4500 bps over such diverse transmission media as wireline and HF radio. To cope with the different media characteristics encountered over wireline and HF radio for example, Collins Radio provides 3 standard modems; the four-tone TE-216A-4, the eight-tone TE-216A-8 and the twenty-tone TE-216A-20. The parameters of each of the modems are matched to the media and data characteristics. Except for the differences in pulse length, delay tolerance, the number of data tones and the number of bits per data tone, all modems are identical in electrical design. Circuit cards and modules are identical except for the frequency determining elements.

Data transmission at conventional data rates is provided by standard modems. Two of the standard modems, the TE-216A-4 and the TE-216A-20, are electrically compatible with existing Collins data modems. The TE-216A-4 is compatible with the TE-207 and TE-210; the TE-216A-20 is compatible with the SSQ-29, AN/ACQ-2, and the TE-202. The third modem, the TE-216A-8 is recommended for general data transmission over HF and provides reliable service at a price significantly lower than the TE-216A-20, primarily because of the fewer number of tones used.

The major characteristics of the three modems are listed below:

Table 1-1

MODEM	NO. OF TONES	PULSE LENGTH	GUARD TIME	DATA RATE (2 CH/TONE)	(3CH/TONE)
TE-216A-4	*4*	*3.33 ms*	*1.06 ms*	*2400*	*3600*
TE-216A-8	*8*	*6.67 ms*	*2.12 ms*	*2400*	*3600*
TE-216A-20	*20*	*13.33 ms*	*4.24 ms*	*3000*	*4500*

For applications which cannot be fulfilled by the standard modems, modems can be custom designed. Automated design techniques afford rapid and efficient processing of customer specifications to final modem specifications and design. The family of circuit cards and modules have been designed so that tone frequencies, pulse timing, delay tolerance, the number of tones, the number of bits per tone can be chosen to provide a wide range of data rate and channel characteristics with the same basic circuits and modules. Design guides and charts are included in Section 4 along with directions and an explanation on their use.

MECHANICAL DESCRIPTION

The family of Data Modem(s) is available in a variety of mechanical configurations, designed to meet a wide range of customer requirements. This flexibility is made possible through the use of standard modular plug-in circuit cards in all configurations. The modems are available in cabinet, self-enclosed drawer and ATR configurations, with appropriate cooling provided for each type of installation. The environmental characteristics vary for each configuration, varying from commercial equipment to MIL-SPEC capabilities.

Modular Circuit Cards

The printed circuit cards used are of two sizes. The first type are 4″ x 6″ cards, with double-sided etched circuitry on 1/16″ glass-cloth epoxy-base laminates. These circuit cards are plug-in by means of an edge-type connector tab which mates with a standard connector in the card cage.

The second type are 3″ x 3″ cards, with single-sided etched circuitry on a 1/16″ paper base, epoxy-filled laminate. These cards are plug-in by means of a 15-pin male connector on the card which mates with a 15-socket connector mounted in the card cage.

Circuit Card Cooling

The modems employ a unique cooling method, which may best be described as a "parallel-flow" or "grid-cooling" system. By this method, cooling air is delivered directly to heat sensitive components on each circuit card.

Circuit card cages are constructed to provide an air plenum along each side of a row of cards, with adjacent rows of cards sharing a common plenum. A series of orifices is provided opposite each edge of each circuit card in the card cage, so that the air is directed to the heat sensitive components on the circuit cards. The air is then exhausted away from each card without passing over any other cards. In effect, each circuit card is provided with ambient cooling air.

Equipment Cabinet Installation

The equipment cabinet installation is the standard commercial version of the Modem family. Horizontal rows of printed circuit cards are mounted in a distinctive equipment cabinet. This cabinet has been especially designed for the Collins "parallel-flow" or "grid-cooling" system. The basic structure consists of two vertical extruded members, which serve as vertical air plenums, and to which the card cages, blower housings, doors and all other structural parts are mounted. The cabinet can be used as a single free-standing unit or attached to one or more other cabinets. A single cabinet, including side panels, is 29¼ inches wide x 13 inches deep x 76 inches high, as shown in Figure 1-1.

Where Collins C-8000 series equipment is in use, modems of the TE-216 family can be installed directly into existing cabinetry where space is available.

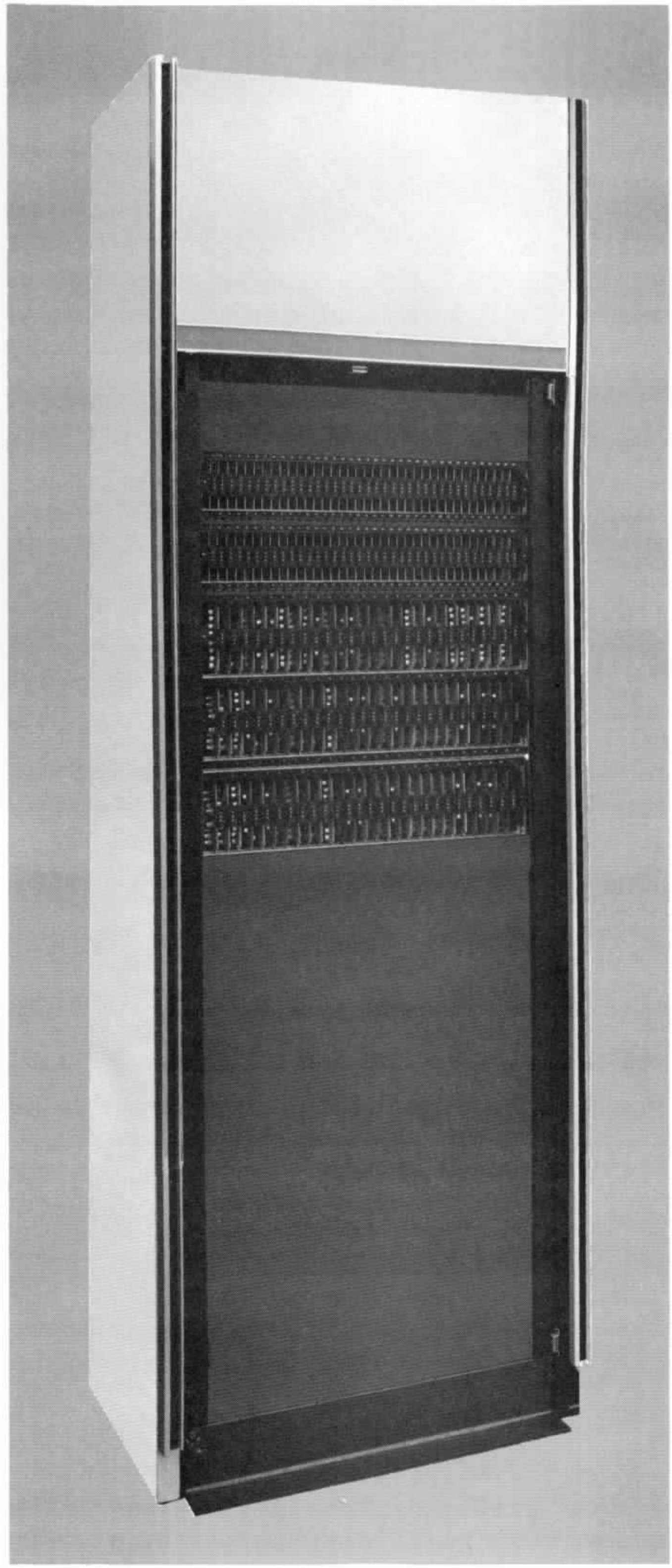


Figure 1-1. Cabinet Configuration.

Self-Enclosed Drawer Installation

The self-enclosed rack-mountable drawers shown in Figures 1-2 and 1-3 are the military version of the Modem family. This drawer version has been especially designed for extreme environmental conditions, and features a closed cycle, forced air system. A counter-flow air-to-air heat exchanger serves as the means of heat rejection. Cooling air is supplied to each individual card by means of the unique card cage design, and after passing over the cards, the air is passed through the air-to-air heat exchanger and recirculated to the circuit cards.

The case is designed to meet military environmental requirements for temperature, humidity, altitude, shock, vibration and RFI.

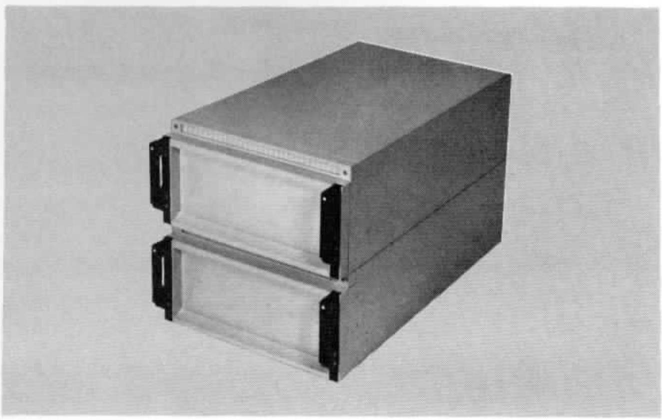


Figure 1-2. Drawer Configuration.

ATR Case Installation

The standard airborne packaging of the Modem family is shown in Figures 1-4 and 1-5. This version employs the same modular circuit cards as all other TE-216 Series modems, but differs in the cooling system employed.

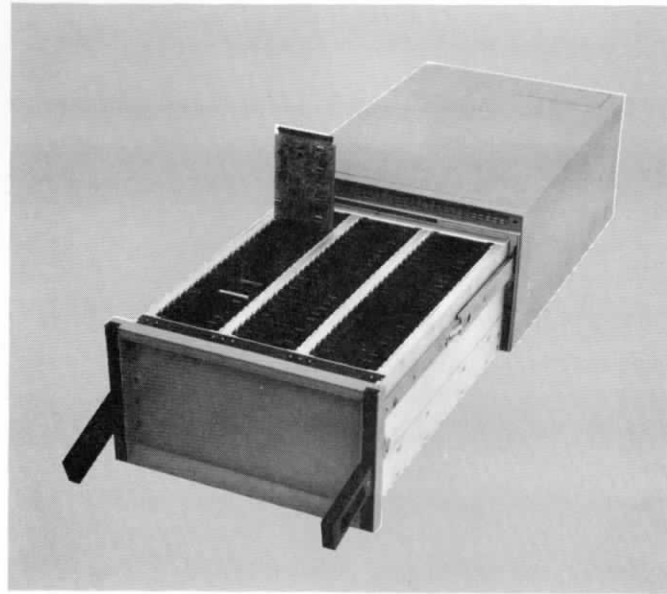


Figure 1-3. Drawer Configuration.

This cooling method is a negative pressure, non-recirculating system utilizing compartment air drawn through the cases by an external blower. The individual cases are installed on MIL-STD isolated mounting bases, which also serve as a common duct for the cooling system.

Optional Installations

Other modem packages are available to suit a wide variety of system applications. Among these are a slide-mounted drawer configuration for standard 19 inch wide cabinets or relay racks. These may have self-contained cooling systems, as shown in Figure 1-6, or may operate on the cooling air supplied by the cabinet, depending on the installation. The modular equipment concept employed can be adapted to a virtually unlimited range of package configurations and environments.

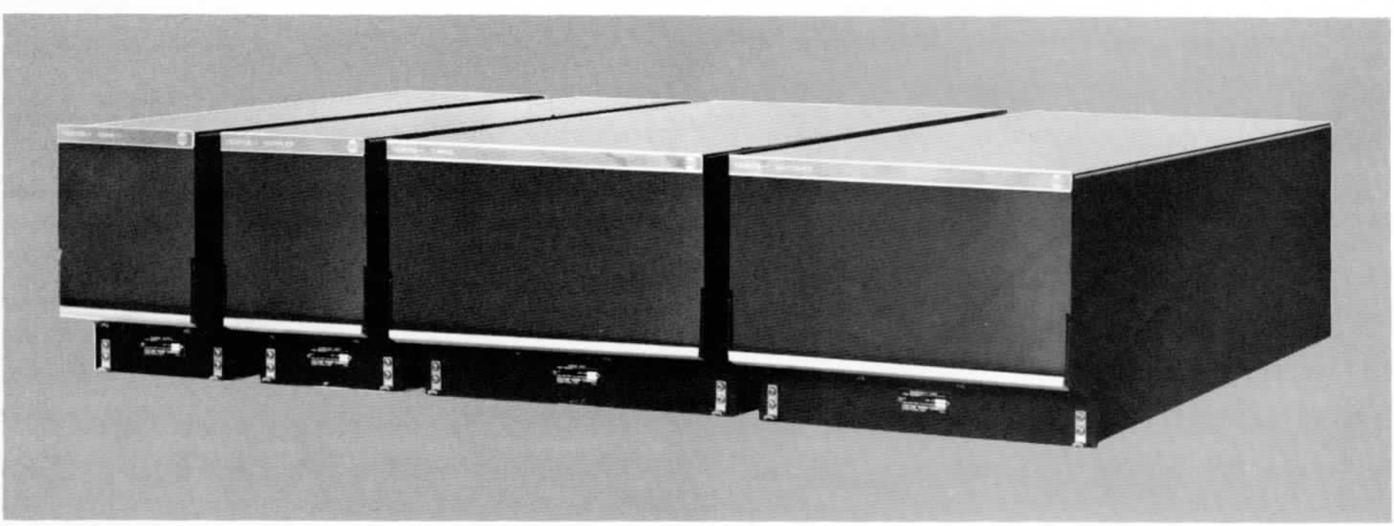


Figure 1-4. ATR Configuration.

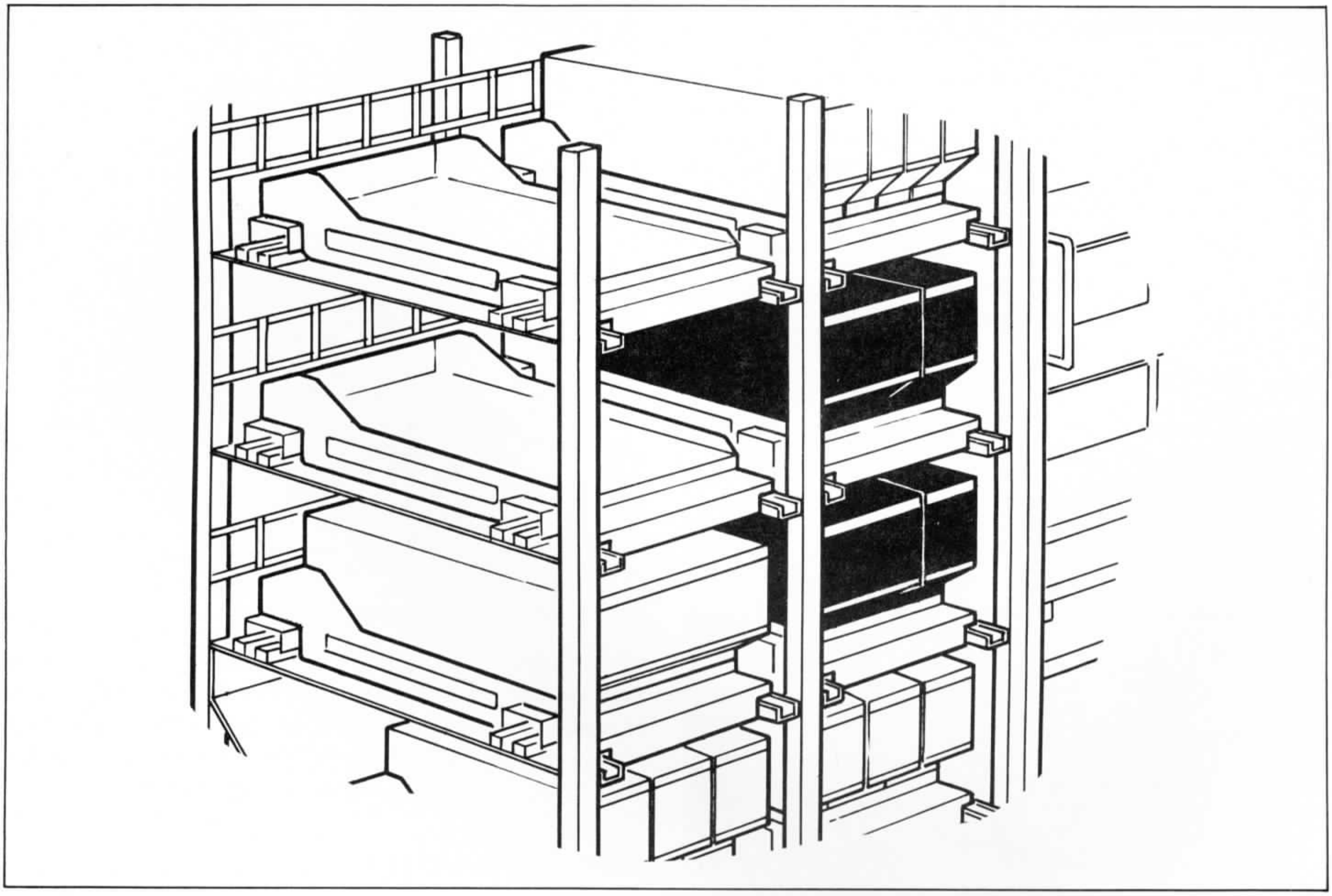


Figure 1-5. Airborne ATR Rack Installation.

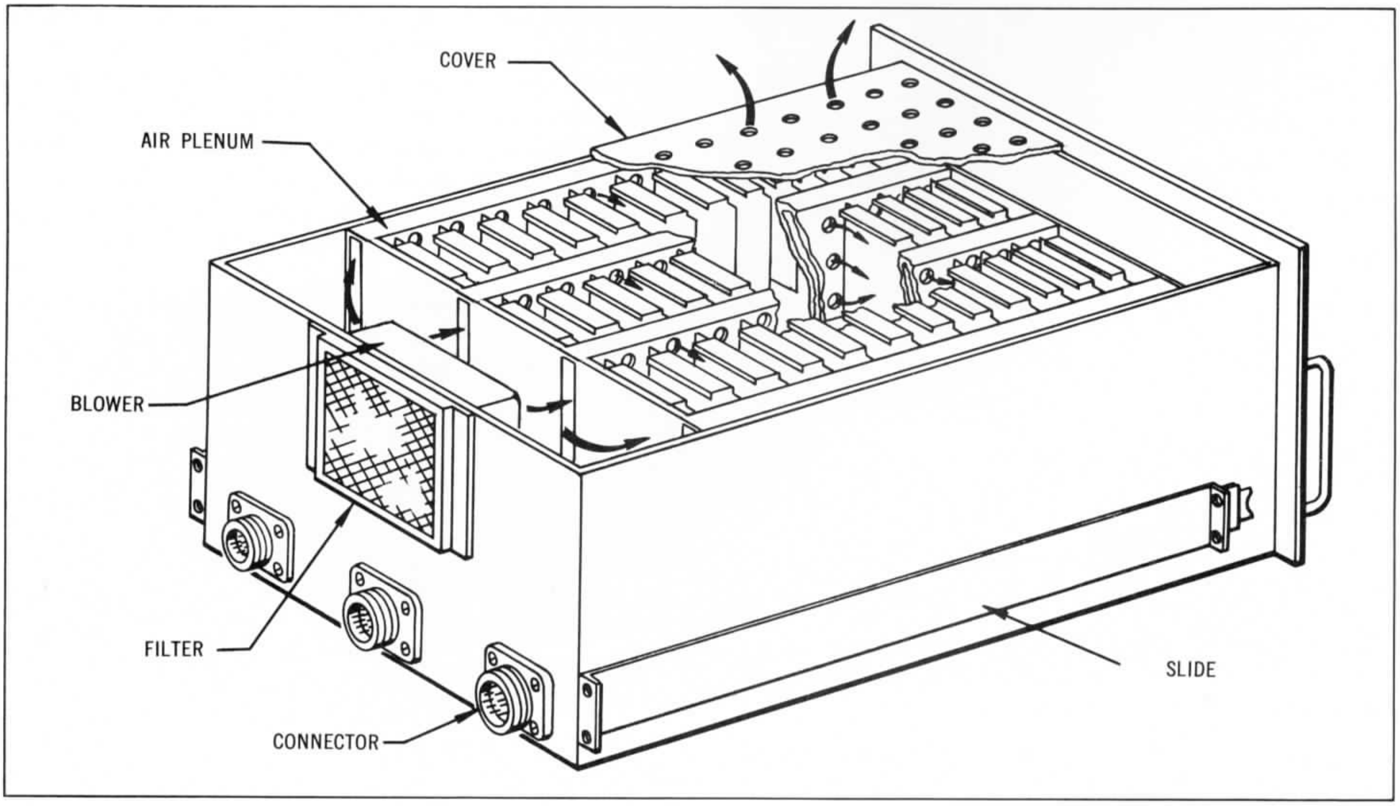


Figure 1-6. Typical Drawer Air Cooling.

section 2

equipment functions and operation

The functional configuration of the TE-216 modems is shown in Figure 2-1. Basically, the modulation/demodulation processes are divided into two groups of equipment, the common equipment group and the tone equipment group. In turn, the common equipment and tone equipment groups are divided into the transmit and receive functions. As shown in Figure 2-1 the common equipment group is comprised of the following transmit and receive functions:

Common Equipment

TRANSMIT FUNCTION

1. Transmit heterodyne, combining amplifier, filters and output amplifier.
2. Transmit time base.

RECEIVE FUNCTION

1. Receive heterodyne, AGC amplifier, filter, and distribution gate.
2. Sync detector.
3. Receive time base.

The tone equipment group is divided into the transmit and receive functions and are as follows:

Tone Equipment

TRANSMIT FUNCTION

1. Data tone generator.
2. Tone modulator.

RECEIVE FUNCTION

1. Keyed filter
2. Phase detector
3. Detector-Sampler and data storage.

The common equipment group is required for all modems and is independent of the number of data tones used.

The tone equipment is required for each modem and is dependent on the number of data tones used. One set of tone equipment is required for each data tone used. Regardless of the number of tones employed or the data rate the operation of the transmit and receive functions are identical. A brief description of each function follows:

TONE EQUIPMENT

Data Tone Generator

The data tone generator consists of a crystal oscillator. The output is used by the tone modulator. Over the operating temperature range the tone generator crystal oscillators are designed to have no more than one cycle difference between any of the tone oscillators and the transmit heterodyne oscillator.

Tone Modulator

The individual tone modulator shown in Figure 2-1 accepts three channels of binary data, an on/off control signal, transmit timing and a tone frequency. The modulator encodes amplitude modulation, and phase modulation in accordance with the input data each transmit timing interval. The modulator includes data storage for one timing interval so that data need be present only at the sampling time as discussed above.

Keyed Filter

The keyed filters shown in Figure 2-1 accept the composite signal frequency and receive timing inputs to separate the individual subcarrier tones. Each filter consists of two separately gated crystals. At the end of one drive interval the phase and amplitude of the driven filter is compared with that of the ringing filter in the data detectors. At the end of the drive interval the driven crystal contains only the frequency of the input to which it is tuned; all other frequencies of the composite signal are at a null in the crystal at that instant. In addition to this separating function, the gated crystal maximizes the peak signal to rms noise ratio at the end of the drive interval and is therefore an implementation of a matched filter. Following the drive interval, the crystal stores the amplitude and phase of the input signal during its ring cycle. Following the ring interval, the crystal is quenched by the application of negative feedback which dissipates the stored signal energy.

The necessary amplifiers for driving and quenching each of the set of two crystals are included on one 4 × 6 circuit card with the crystals. The only frequency sensitive elements are the crystals themselves which are interchangeable among any of the circuits.

Phase Detector

The phase detector accepts the output of the two keyed filters and generates an output which is proportional to the phase difference between the two inputs. An identical phase detector is provided for the inphase and quadrature channel.

Each phase detector accepts inputs from each keyed filter as shown in Figure 2-1. The inputs to be detected consist of the ringing and driven crystal outputs as selected by the timing inputs. The relative phase and amplitude of the ringing crystal (previous pulse) and driven crystal (present pulse) are measured in conventional phase and amplitude detector circuitry.

The detectors for the 2 PSK channels on one subcarrier are contained on one 4 × 6 circuit card.

Detector Sampler and Data Storage Unit

The detector sampler unit samples the output of the inphase and quadrature phase detector at the sampling time, quantizes the analog voltage to a binary one or zero, and stores the resulting binary information in two flip/flops. The detector sampler unit also contains the amplitude detector and sampling gates which quantize the output of the amplitude detector and stores the result in an output flip/flop.

The DSU including the 3 data output storage F/F is contained on one 4 × 6 circuit card.

Transmit Heterodyne, Combining Amplifier and Filters

The combining amplifier shown in Figure 2-1 accepts the individual outputs of the tone modulators and combines them into a composite signal. The tone modulator outputs are phase shifted, amplitude modulated square waves, and the combining amplifier serves the additional purpose of filtering the composite square wave signal from its harmonics prior to heterodyning. This minimizes cross-modulation products of the harmonics in the mixer.

The mixer, filter and output amplifier accepts the combining amplifier and the divided heterodyning oscillator outputs and separates and amplifies the composite difference frequency signal. The output amplifier contains an automatic gain control feature which holds the signal peaks within the communication circuit specifications independently of the number of subcarrier tones used. The AGC time constant is sufficiently long to insure negligible amplitude change over a transmit timing interval.

The combining amplifier and filter circuitry is contained on one circuit card; the mixer, filter and oscillator circuitry on one card; and the output amplifier circuitry on one card.

Transmit and Receive Heterodyning

Subcarrier tone frequency stability is improved in the design shown in Figure 2-1 over that obtainable with single, uncompensated crystal oscillators and filters by means of the heterodyning method used in the transmit and receive sections of the modem.

Each transmitted subcarrier originates in a crystal oscillator. To minimize the variation with temperature, the subcarrier tones are mixed with a heterodyning frequency approximately equal to the tone frequencies. The heterodyning oscillator frequency is divided by the same number as the tone oscillator frequency to allow the use of a crystal similar in characteristics to the tone oscillator crystals. These crystals make up a set, each of which have matched frequency/temperature characteristics. The difference frequencies resulting from the mixing of the subcarrier tones with the heterodyning frequency therefore exhibit only a fraction of the variation of any individual frequency. Variations in the frequency spacing of the tones are likewise reduced. The resulting frequency error of the output frequencies is about one c/s for the voice band modem.

The temperature variation of the tone filters in the receive section is likewise reduced by matching the receive heterodyning oscillator crystal to the tone filter crystals.

Receiver Heterodyne, AGC Amplifier, Filter and Distribution Gates

The receiver AGC amplifier accepts the composite input signal and controls it to a level suitable for the tone filters. It will operate satisfactorily for signal levels between +10 dbm and −30 dbm.

The output of this amplifier is mixed to the tone filter frequencies in the mixer and spurious frequencies are removed by a filter. The output of this filter is gated in two phases by the distribution gates to drive the tone filters and also is accepted by the receiver synchronization detector.

The AGC amplifier circuitry is contained on one circuit card; the mixer, filter and oscillator circuitry on one card; and the distribution gates and amplifiers on one card.

Transmit and Receive Timing

Transmit and receive timing are generated independ-

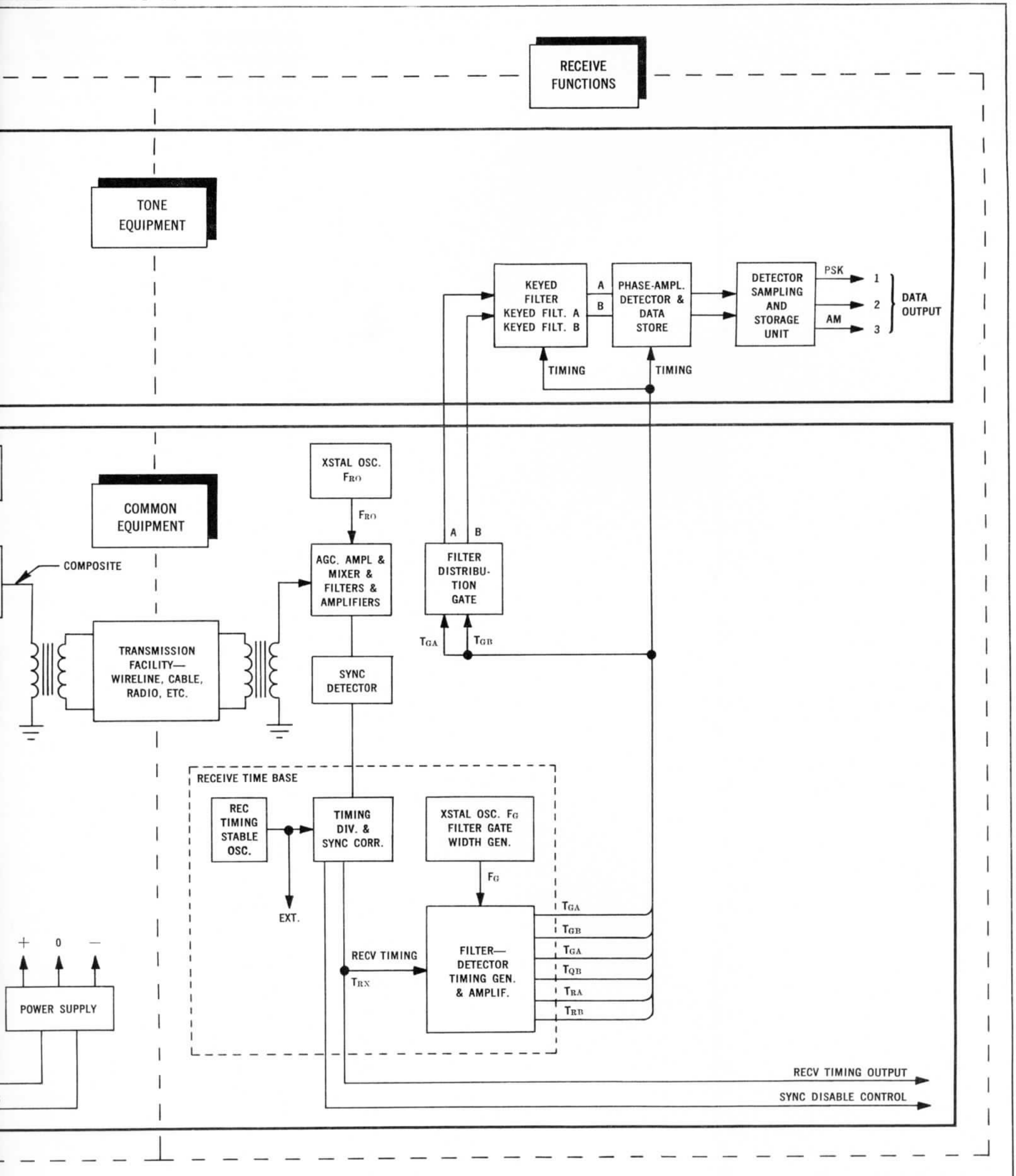
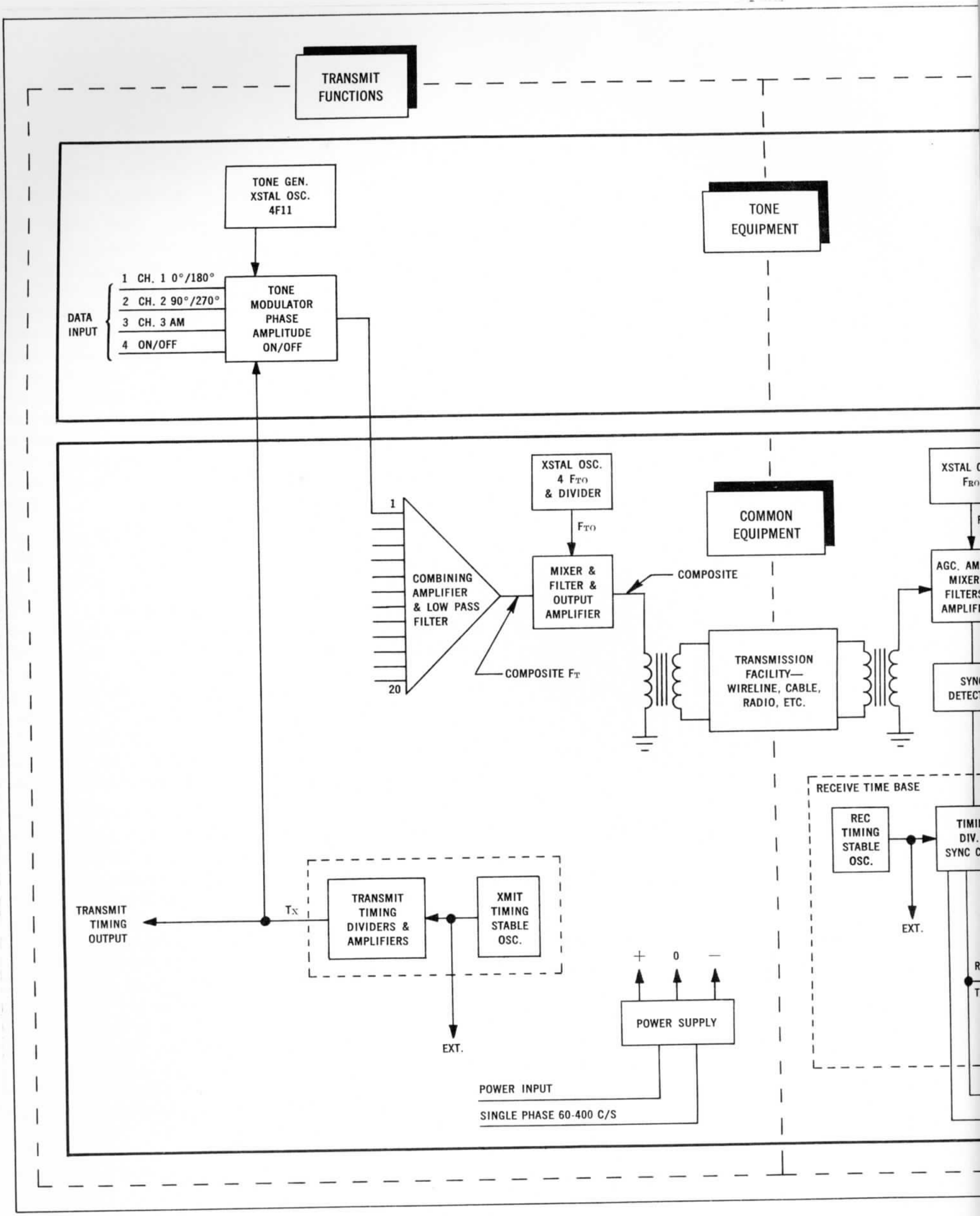


Figure 2-1. Block Diagram.



TRANSMIT FUNCTIONS
TONE EQUIPMENT
COMMON EQUIPMENT
TONE GEN. XSTAL OSC. 4F11
DATA INPUT
1 CH. 1 0°/180°
2 CH. 2 90°/270°
3 CH. 3 AM
4 ON/OFF
TONE MODULATOR PHASE AMPLITUDE ON/OFF
XSTAL OSC. 4 FTO & DIVIDER
FTO
1
20
COMBINING AMPLIFIER & LOW PASS FILTER
MIXER & FILTER & OUTPUT AMPLIFIER
COMPOSITE
COMPOSITE FT
TRANSMISSION FACILITY— WIRELINE, CABLE, RADIO, ETC.
RECEIVE TIME BASE
REC TIMING STABLE OSC.
EXT.
TRANSMIT TIMING OUTPUT
TX
TRANSMIT TIMING DIVIDERS & AMPLIFIERS
XMIT TIMING STABLE OSC.
EXT.
+
0
−
POWER SUPPLY
POWER INPUT
SINGLE PHASE 60-400 C/S

ently to allow full duplex operation. The timing dividers for the transmit and receive timing are however identical to allow the use of only one timing oscillator in applications where the transmitter and receiver operate in the same timing mode.

The transmit timing circuitry divides the stable oscillator input to a square wave of period Tx used for sampling data into the tone modulators and providing external equipment with the modem timing.

The receive timing circuitry consists of two basic timing generators. One generator is synchronized to the input signal and generates the receive timing, T_{RX}, from the receive timing oscillator. The second generator derives the tone filter and detector timing wave forms from a crystal oscillator. This second generator is started by the receive timing generated by the first, and therefore the filter-detector timing wave forms are always fixed with respect to the receive timing. The purpose of the two separate generators is to allow independent adjustment of the receive timing and the filter gate width and thus provide any amount of guard for any specified filter gate width.

The receive timing generator consists of a controlled divider used to synchronize the divided output of the stable timing oscillator to the detected synchronizing signal.

The division ratio is approximately 100, and one oscillator count is added or deleted for each on/off cycle of detected synchronization signal. This allows synchronization within one percent and assures good averaging of perturbed synchronization signals. The receive timing output is a square wave of duration T_{RX}, and is delivered both as an output to external equipment and to the filter-detector timing generator.

The filter-detector timing generator divides the output of a crystal oscillator into timing waveforms used in the tone filter distribution gates, the tone filters and the phase-amplitude data detectors. This timing generator starts dividing when triggered by the receive timing and continues until the appropriate waveforms have been counted out. These waveforms are then distributed in three phases derived from the receive timing input. The division ratio is approximately 100 to insure that the gating waveforms lag the receive timing input by less than one percent of their interval. The timing waveforms derived from this generator are amplified prior to delivery to the tone filters and detectors to avoid individual amplification in each of those circuits.

Sync Detector

The sync detector derives its timing information from the composite data signal. No special modulation is required nor is a separate tone or guard band required. The functioning of the sync detector is independent of the data content and is also independent of the number of data tones used. A keyed filter pair is used to sense the time difference between the receive time base and the receive data signal. Drive timing for the keyed filter pairs are derived from the receive time base.

This technique utilizes keyed crystal resonators tuned to an out-of-band frequency. This frequency, and the gating period of these resonators, are selected so that when the system is synchronized no output is obtained from the resonators. A shift in timing will result in an output in one or the other resonator which generates a correction voltage for resynchronizing. Figure 2-2 is a functional block diagram of the sync detector. Figure 2-3 presents pertinent waveforms. In the out-of-sync situation one of the resonators begins straddling the phase transitions. This causes crosstalk energy from the data tones to appear in that resonator which is reflected by a ringout voltage.

The envelope detector and integrator sense which resonator has the higher ringout energy and corrects accordingly.

The sync detector requires three circuit cards per sideband.

Table 2-1 summarizes the tone equipment and common equipment functions and the number of circuit cards associated with each function.

Table 2-1

TONE EQUIPMENT FUNCTION	CIRCUIT CARDS/TONE
Tone Generator and Modulator	*2*
Keyed Filter Pair	*1/sideband*
Phase Detector	*1/sideband*
Detector Sampling and Data Storage	*1*
COMMON EQUIPMENT FUNCTION	**CIRCUIT CARDS/TONE**
Transmit Heterodyne and Output Amplifier	*2*
Combining Amplifier	*1*
Transmit Time Base	*13*
Receive Heterodyne, AGC Amplifier, and Distribution Gate	*3*
Receive Time Base	*33*
Sync Detector	*3/sideband*

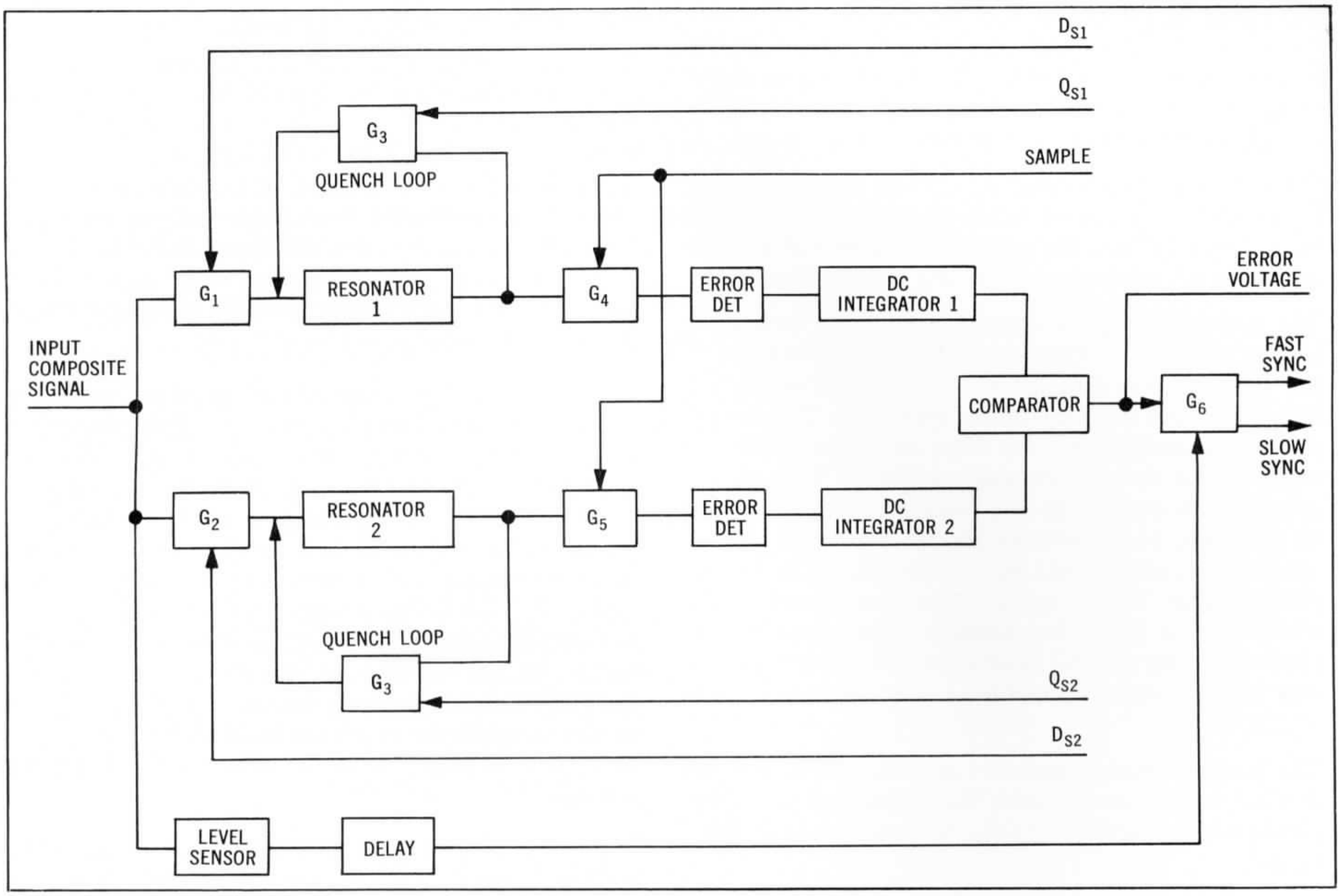


Figure 2-2. Modem Synchronization Function Diagram.

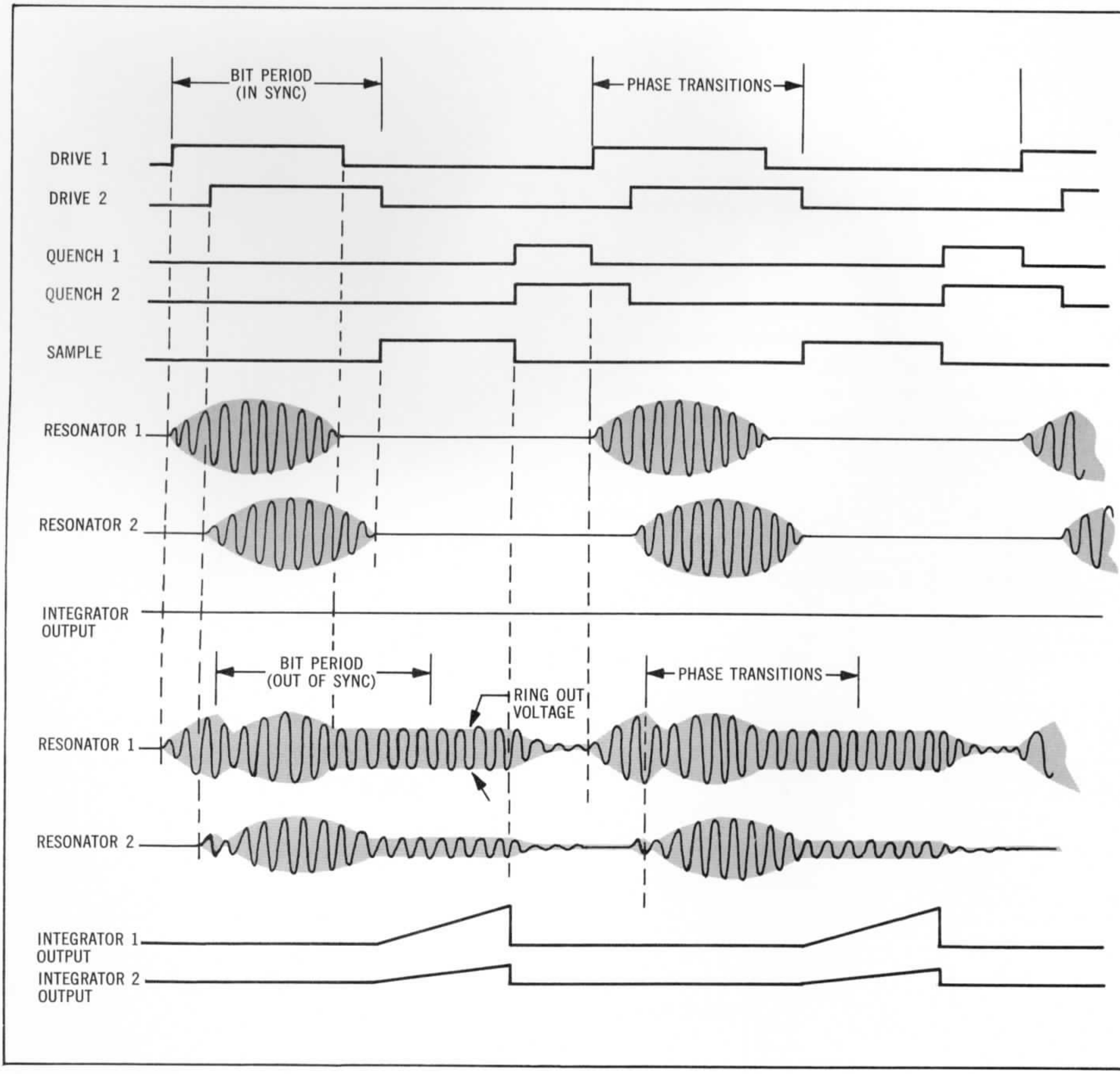


Figure 2-3. Modem Synchronization System Wave Forms.

section 3

recommended TE-216 modems

This section summarizes the TE-216A-4, the TE-216A-8, and the TE-216A-20 Data Modems. Complete equipment specifications are included. Table 3-1 summarizes the major features of each equipment. For further information, refer to the specific product description.

Table 3-1

MODEM	FEATURES	DATA RATE	APPLICATION
TE-216A-4/D4	*Derived voice channel modem delivering 3600 bits/sec.; compatible with TE-210 modem.*	*2400/ 3600*	*Suitable for wireline, cable, microwave applications requiring low error rate performance (1×10^{-5} or better). Also can be used over HF radio circuits with diversity receiver for applications such as digitized secure voice.*
TE-216A-8/D8	*Data rate of 3600 b/s over wireline, cable, microwave or HF at reasonably low error rates.*	*2400/ 3600*	*Suitable for wireline, cable, microwave, and HF radio applications requiring low error rate performance (1×10^{-5} or better).*
TE-216A-20/D20	*Up to 40-75 b/sec. channels in voice bandwidth. Excellent performance over HF radio.*	*3000/ 4500*	*Primarily designed for HF radio circuits requiring maximum system performance.*

section 4

design guides

Included in this section are design guides and charts which will aid the engineer in specifying modems of the TE-216 family for applications which cannot be fulfilled by the standard TE-216 modems. Because of the interdependency of the modem characteristics the major parameters and their effect upon performance also are discussed. The most important considerations are:

1. Number of data tones,

2. Pulse length and guard time,

3. Frequency errors,

4. Frequency stability of timing oscillator.

Number of Data Tones

The number of data tones used should always be as low as possible for a given data rate and associated media characteristics, because the cost and complexity of the Tone Equipment is directly proportional to the number of data tones used.

Pulse Length and Guard Time

The pulse length is the reciprocal of the keying rate. In keeping with the requirement of employing the least number of data tones, the pulse length should be as short as possible. The guard time is related to the pulse length as shown in Figure 4-1.

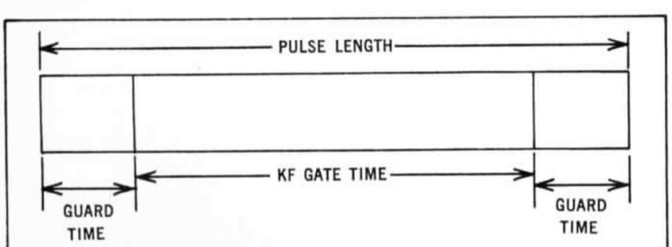


Figure 4-1. Pulse Length and Guard Time.

At the receiver, the guard time provides protection against differential delay, sync jitter and multipath. For wireline and similar media a guard time of 1 msecond is usually satisfactory. For HF radio media guard time can be between 1 msecond-4 mseconds or more. The exact choice depends upon radio equipment characteristics, the mode of operation, the type of data. For fixed station, general data use, a guard time of 2 mseconds or greater will provide reliable performance.

In general, the greater the guard time, the more tolerance the modem will have to differential delay, sync perturbations, and multipath delay. However, the S/N performance will degrade proportionately. For example, if the guard time is increased from 1 ms to 2 ms, the S/N performance will degrade. Therefore, the guard time should be as short as possible.

Frequency Errors

Frequency errors can be caused by several sources.

1. Doppler shift because of relative motion between transmitter and receiver.

2. Tone generator inaccuracy.

3. Differences in the transmitter and receiver heterodyne frequencies; radio and modem.

4. Receiver Keyed Filter detuned.

In each case the effect is the same—a decrease in S/N performance. In general, the degradation is proportionately greater the longer the pulse and the integration time. For example, corresponding to one db of degradation a 4-tone system will tolerate about 50% more frequency deviation than an 8-tone system.

The mathematical relationship between the number of data tones, data rate, guard tone and bandwidth is presented in the following equations and illustrated in graphical form in Figure 4-2. Figure 4-3 is a graph showing the effect of frequency errors as a function of the number of data tones for a bandwidth of 2400 cps.

$D =$ data rate in bits/second,

$n =$ number of data tones,

$c =$ channels/tone 2 or 3,

$P =$ pulse time in seconds $= G + I$,

$G =$ guard time in seconds,

$I = \text{KF gate time in seconds} = \frac{1}{F}$

$F = \text{tone spacing in cps},$

$$D = \frac{1}{P}(nc)$$

$$D = \frac{nc}{G + I},$$

$$F = \frac{B}{n+1} \text{ and } I = \frac{1}{F} = \frac{n+1}{B},$$

$$\text{Therefore, } D = \frac{nc}{G + \frac{n+1}{B}} \qquad \text{(Equation 4-1)}$$

← B (cps) = F (n + 1) →
3 db Bandwidth
l l l l
n tones spaced F
cycles apart.

Frequency Stability of Timing Oscillators

Some applications may require that the receiver be able to operate without the benefit of continuous sync. For instance, during radio silence the receiver will have to maintain timing information between transmissions.

The interval over which synchronism can be held between synchronizing transmissions is a function of the stability of the transmit and receive timing oscillators and the modem data rate. To hold within an E% synchronization accuracy the following relationship holds:

$$T = \frac{N/\text{data rate}}{\Delta f/f} \times \frac{E}{100}$$

N = Number of parallel data channels = (number of tones) × (channels per tone) = nc.

$\Delta f/f$ = Fractional frequency error between the transmit timing oscillator and the receive timing oscillator.

T = Maximum interval between synchronizations in seconds.

E = Synchronization error in percent $= \left(\frac{\text{Guard Time}}{\text{Pulse Length}}\right) \times 100$

As an example, assume that $\frac{\Delta f}{f} = 10^{-6}$ and the time interval for the 4-tone TE-210 compatible modem is desired.

$$T = \frac{8/2400}{10^{-6}} \times \frac{(1.06)/3.33 \times 100}{100}$$

$$T = 1.06 \times 10^{3} \text{ seconds} = 17.7 \text{ minutes.}$$

Adaptive Control Capabilities

For any given transmission media, signal perturbations such as impulse noise, bandwidth changes and frequency translation errors can occur over short time periods. The TE-216 line of modems contain control inputs which allow a trade-off of data rate to combat the perturbations. Modem characteristics

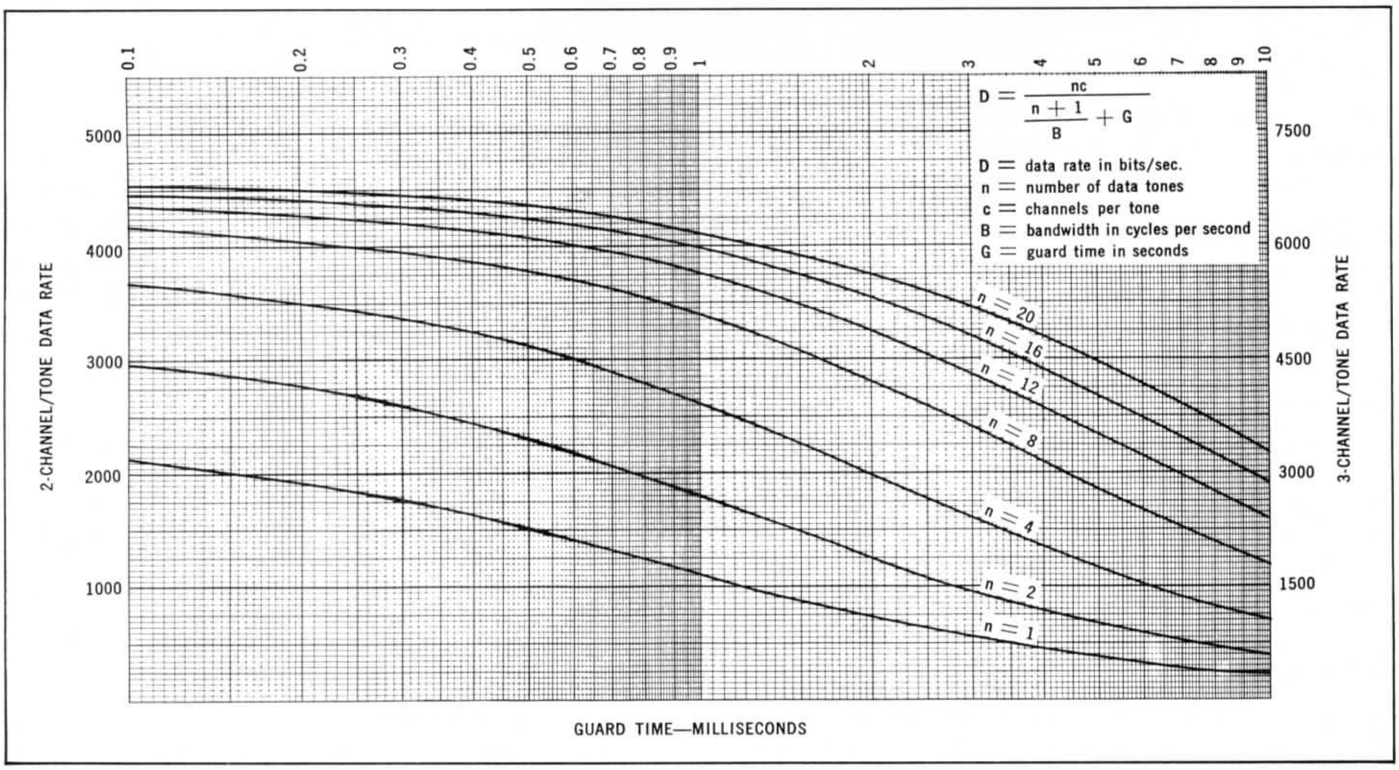


Figure 4-2. System Design Guide for Choosing Guard Tolerance versus Data Rate versus Number of Tones.

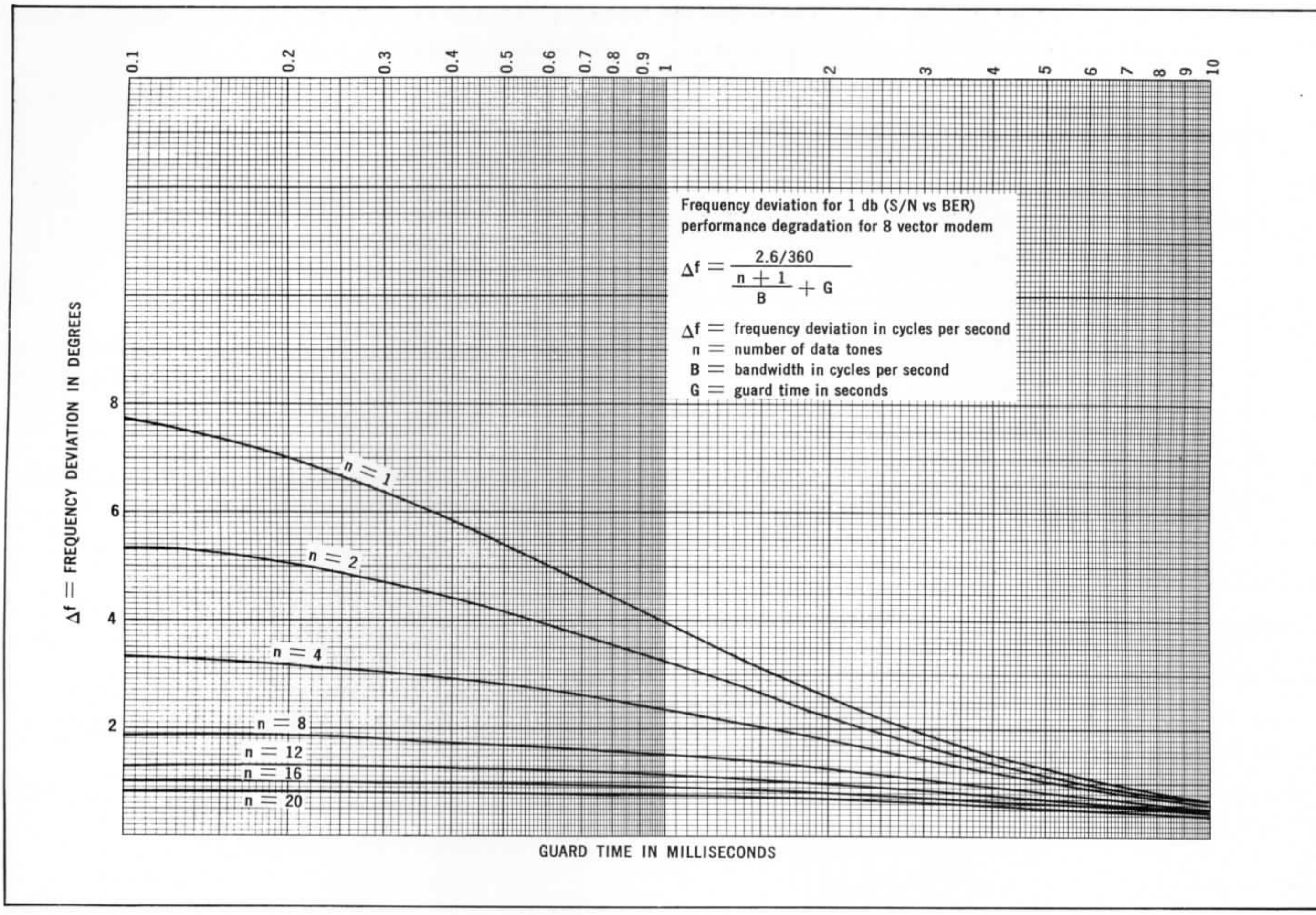


Figure 4-3. System Design Guide for Choosing Guard Tolerance versus Frequency Tolerance versus Number of Tones.

capable of automatic control are the number of subcarrier tones and the number of channels per tone. The control inputs required to change the rate are simple. Each data tone can be switched with its on/off control. To remove data channels per tone only required that that data channel input be held to binary zero.

Changes in differential delay are considered to be primarily installation problems and are handled by changing the timing oscillator card.

Example:

To illustrate the use of the design guides, the following set of customer requirements will be analyzed and a set of modem parameters determined.

Data rates: 3600 bits/second
Transmission media: HF Radio
Radio characteristic (delay): See Figure 4-4
Point-to-point fixed station: 1000 KM apart

The modem parameters that must be specified are:

Number of data tones,
Data tone frequencies,
Data channels per tone,
Pulse length,
Guard time.

Guard Time

From Figure 4-4, the differential delay of the radio can be compensated to better than 800 microseconds. Therefore, allow 1 msecond.

Sync timing jitter over an HF path for worst S/N conditions should not exceed .5 mseconds.

Figure 4-5 shows that at 1000 KM 4 mseconds or more in multipath delay can be expected. Figure 4-6 shows that 2 mseconds delay in the 2-hop component and 4.5 mseconds delay in the 3-hop component can be expected. In general, the larger the number of hops, the greater the attenuation. Therefore, 2 mseconds multipath delay should be satisfactory.

The total guard time allowed is:

$$G = \sqrt{(\text{Differential delay} + \text{Sync tolerance})^2 + (\text{Multipath tolerance})^2}$$

$$= \sqrt{(1.5)^2 + 2^2}$$

$$G = 2.5 \text{ mseconds.}$$

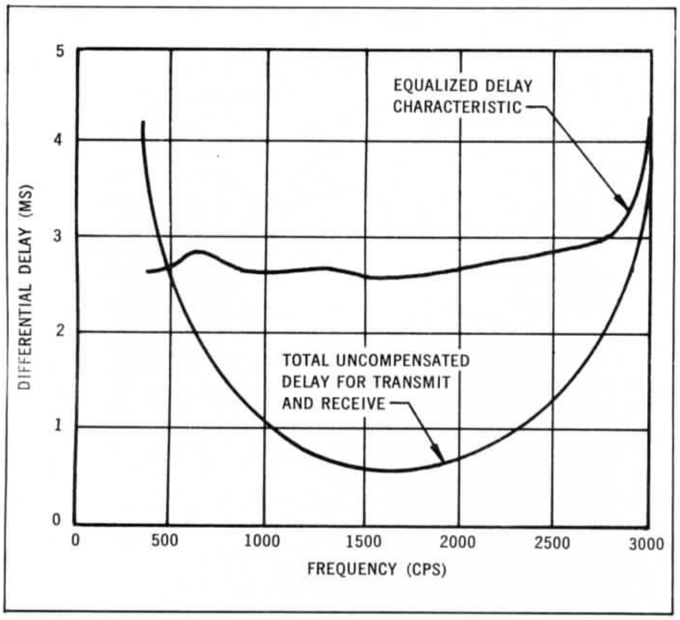


Figure 4-4. URG-1 Radio Differential Delay Characteristic.

Number of Tones

From Figure 4-2, 7 tones wiil provide 3600 bits with three channels per tone.

For an assumed bandwidth of 2400 cps, the 7 tones will be spaced 300 cps apart.

Correspondingly, the integration time is:

$$I = \frac{1}{300} = 3.33 \text{ mseconds.}$$

The pulse length $P = G + I = 2.5 + 3.33$ $= 5.83$ mseconds.

Figure 4-3 indicates that the modem will suffer 1 db of performance degradation for 1.25 cycle of frequency deviation.

The modem characteristics can be specified as follows:

Number of data tones: 7
Tone frequencies: $500 + n\ (300) \quad n = 1 \cdots 7$
Data channels per tone: 3
Pulse length: 5.83 mseconds
Guard time: 2.5 mseconds
Frequency deviation for 1 db degradation: 1.25 cps.

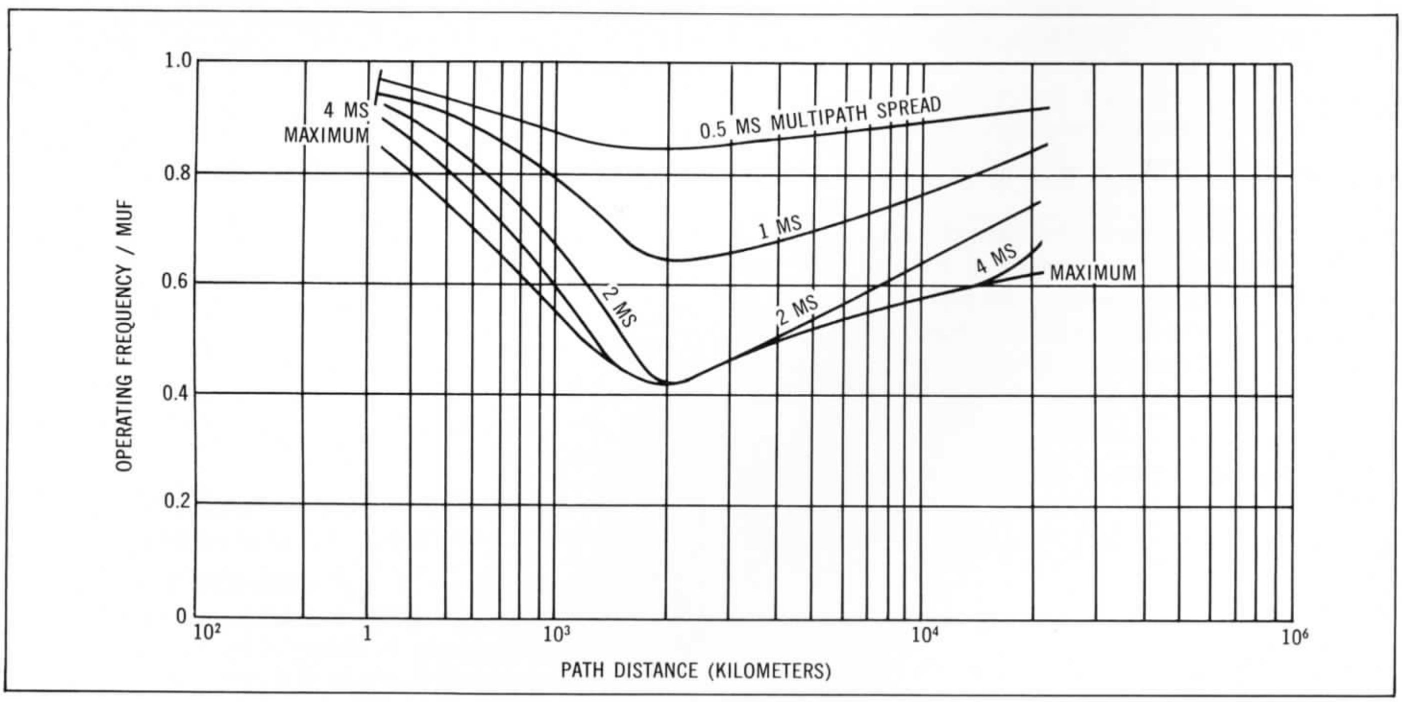


Figure 4-5. Multipath Delay Spread.

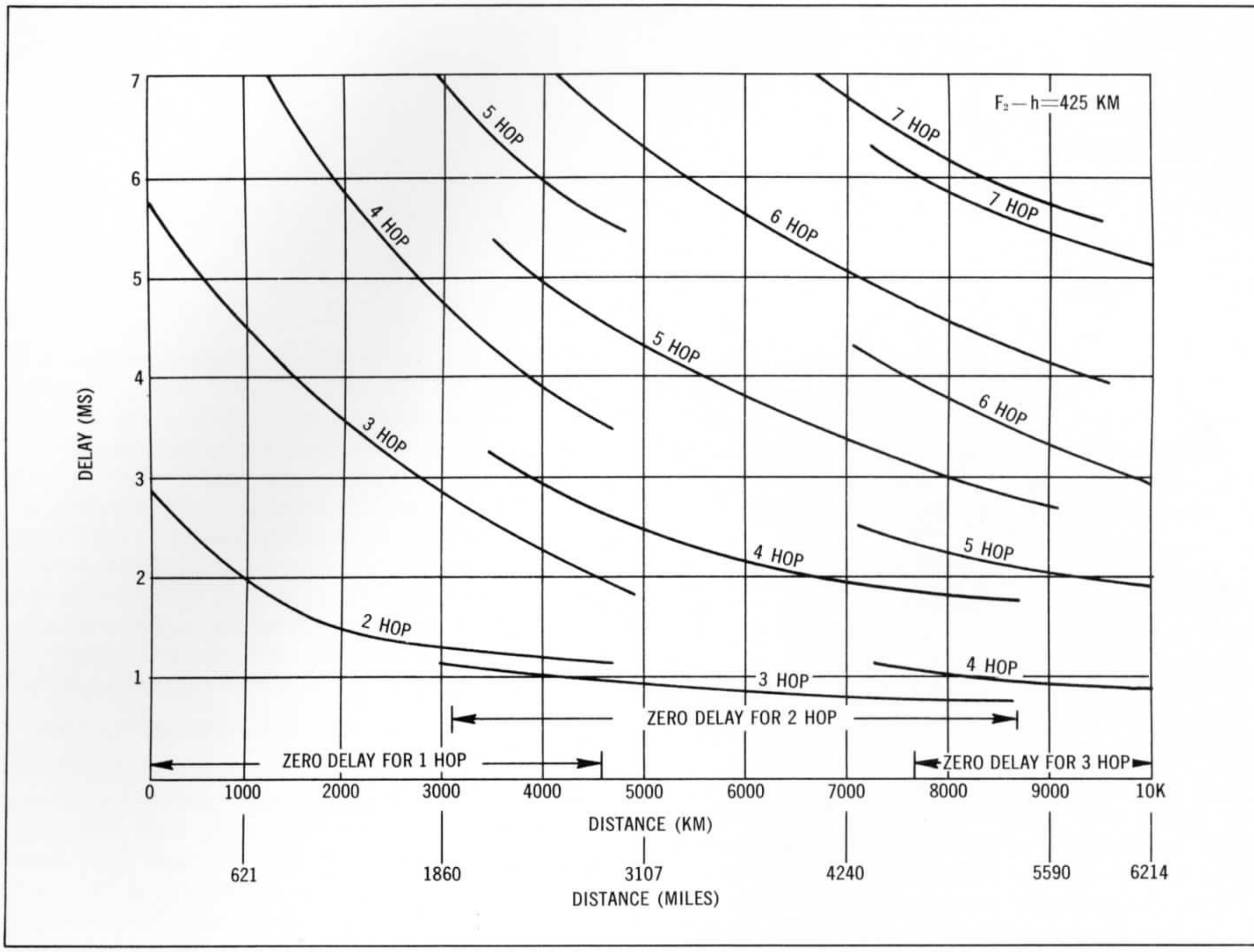


Figure 4-6. Multipath Delay Times.

section 5

TE-217 summary

This section describes a full-duplex digital modem designated the TE-217. The TE-217 modem is designed for a nominal transmission rate of 92,400 bits/second over a 48 kc bandwidth communications channel. The modem transmission rate is variable to provide operating tolerances for compensating communication channel characteristics. Variation of amplitude and phase delay, noise and frequency stability characteristics of the line may be accommodated for by control of the number of data channel tones active, the signal pulse repetition rate and the coding of the digital data on the data tones.

Electrical Characteristics

The TE-217 Modem is a synchronous modem which accepts input binary data channels and encodes the input data into phase-amplitude modulated carrier tones. Four levels of phase modulation and one level of amplitude modulation provides a three-bit transmission signal pulse on each carrier tone.

Appropriate choice of clock frequency establishes the modem input binary data channel rates from 2500 to 3850 bits/second per channel and nets up to a total rate of 92,400 bits/second. The transmitted signal pulse length corresponding to the 92,400 bit/second speed range is 260 microseconds.

External control signals may be applied to the modem to establish a wide range of transmission speed permutations. The number of data tones from one through eight and coding options of two bits (PSK) or three bits (PSK + AM) per pulse are operational modes selectable by external control to the modem.

Degraded communication channel characteristics may be tolerated by selection of the suitable operating mode. The variation of the net transmission rates as a function of the number of data tones in use for constant envelope delay tolerance may be selected for proper system operation.

Phase and amplitude coding of the carrier tones is accomplished in the tone modulators. Two binary bits are phase coded by advancing the phase of the signal pulse relative to the preceding signal pulse 0°, 90°, 180° or 270° depending on the four permutations of two input binary bits. A third input binary bit to the tone modulator is amplitude modulated on the signal pulse resulting in eight levels of modulation on each data tone.

For further information refer to the specific product description.

section 6

TE-218 summary

This section describes a full-duplex digital modem designated the TE-218. The TE-218 modem is designed for a nominal transmission rate of 460,800 bits/second over a 240 kc communications channel. The modem transmission rate is variable to provide operating tolerances for compensating communication channel characteristics. Variation of amplitude and phase delay, noise and frequency stability characteristics of the line may be accommodated for by control of the number of data channel tones active, the signal pulse repetition rate and the coding of the digital data on the data tones.

Electrical Characteristics

The TE-218 Modem is a synchronous modem which accepts input binary data channels and encodes the input data into phase-amplitude modulated carrier tones. Four levels of phase modulation and one level of amplitude modulation provides a three-bit transmission signal pulse on each carrier tone.

Appropriate choice of clock frequency establishes the modem input binary data channel rates from 12,500 to 19,200 bits/second per channel and nets up to a total rate of 460,800 bits/second. The transmitted signal pulse length corresponding to the 460,800 bit/second speed range is 52 microseconds.

External control signals may be applied to the modem to establish a wide range of transmission speed permutations. The number of data tones from one through eight and coding options of two bits (PSK) or three bits (PSK + AM) per pulse are operational modes selectable by external control to the modem.

Degraded communication channel characteristics may be tolerated by selection of the suitable operating mode. The variation of the net transmission rates as a function of the number of data tones in use for constant envelope delay tolerance may be selected for proper system operation.

Phase and amplitude coding of the carrier tones is accomplished in the tone modulators. Two binary bits are phase coded by advancing the phase of the signal pulse relative to the preceding signal pulse 0°, 90°, 180° or 270° depending on the four permutations of two input binary bits. A third input binary bit to the tone modulator is amplitude modulated on the signal pulse resulting in eight levels of modulation on each data tone.

For further information refer to the specific product description.

section 7

common carrier wideband data

General

Wideband high speed data service offered by AT&T is tariffed in FCC 250. The services are referred to in FCC 250 as Telpak A, Telpak C, and Telpak D.

The table below lists salient facts on each of these services.

Telpak A

The serial 40.8 K bits/second service is provided by a single tone, 4-phase modem, identical in design concept to the 2000-2400 b/s AT&T 201B subset employed on voice bandwidth service. The 40.8 K bit subset has carrier positioned at 30.6 kc and a transmission bandwidth requirement of 10 to 50 kc. Performance estimates extrapolated from data on the 201B set in voice bandwidths would indicate 2 db degradation of performance with envelope delay variation at 10 kc and 50 kc points equal to the transmitted pulse length (50 microseconds).

The line signals are transmitted from the subscriber premises to the central office with repeatered cable circuits where the band is translated into the basic carrier group range of 60 to 108 kc. Carrier group filters 60 to 108 kc are indicated to have a differential delay of 100 microseconds (64 to 104 kc). Equalization is added for data service.

Telpak C

Telpak C service provides seven parallel data channels with 15,000 bit/sec/channel rate capability or 105,000 bit/second total rate.

Each channel is DSB-AM modulated and uses a bandwidth of approximately 30 kc. The seven channels have line frequencies spaced in the 312 to 552 kc range which corresponds to a super group assignment on L carrier. The modem is located at the customers premise and if the distance to the central office is under eight to 10 miles, 22 gauge cable pair is used on the local loop. Repeaters are required at one-mile spacings. Video grade facility is desired if the local loop exceeds 10 miles.

L carrier specifications indicate that equalization is incorporated for data transmission; with equalization, delay characteristics of less than 50 microsecond variation over 225 kc, of the 240 kc super group, is obtained through 10 links.

Telpak D

This service offers seven data channels, each with a data rate capability up to 62,500 bits/second. The modem is located at the central office. Seven independent 10 cps-100 kc special equalized lines are required from the subscriber premises to the central office.

Each data channel is DSB-AM modulated on an independent tone. Each data tone is assigned a 240 kc bandwidth channel (total bandwidth 1,848 kc) over an L carrier system.

section 8

application notes on synchronous multichannel equipment

These notes on synchronous multichannel equipment standards were compiled for consideration by system design personnel.

BIT—A bit shall be the smallest basic unit of binary data transmission the two states of which shall be identified as "one," which shall be equivalent to "mark," and "zero," which shall be equivalent to "space."

FRAME INTERVAL OR TRANSMITTED DATA PULSE LENGTH—For 4 vector (a sub channel). A standard incremental data rate of (75) x 2^n bits per second gives the following:

BITS PER SECOND	TRANSMITTED PULSE LENGTH IN MILLISECONDS	
	SHORT TERM STABILITY Plus or Minus One Part in Ten to the Third	LONG TERM STABILITY Plus or Minus One Part in Ten to the Eighth
45.45 (Note 1)	*22.00*	
75.00	*13.33*	
150.00	*6.666*	
300.00	*3.333*	
600.00	*1.666*	
1,200.00	*0.8333*	
1,300.00 (Note 2)	*0.7692*	
2,400.00	*0.4166*	
2,600.00 (Note 2)	*.3846*	
4,800.00	*0.2083*	
5,400.00	*0.1851*	

Note 1: Special for 60 wpm synchronous TTY, 7.0 bit characters
Note 2: Special for SAGE, 325 x n

The short term stability of plus or minus one part in ten to the third requires the receiver to continuously synchronize. When conditions are variable or there is interference it is desirable to synchronize only during good periods and have whatever long term stability is necessary to maintain the system timing over the poor periods. Plus or minus one part in ten to the eighth is sufficient timing stability for 24 hour gaps.

Subcarrier Frequencies

Audio frequencies used in the General Kineplex Phase-Shift Equipments are as follows:

SUBCARRIER NUMBER	SUBCARRIER FREQUENCIES (110 CPS SPACING) (NOTE 4)
1	*605*
2	*715*
3	*825*
4	*935*
5	*1045*
6	*1155*
7	*1265*
8	*1375*
9	*1485*
10	*1595*
11	*1705*
12	*1815*
13	*1925*
14	*2035*
15	*2145*
16	*2255*
17	*2365*
18	*2475*
19	*2585*
20	*2695*
21	*2805*
22	*2915*

Note 4: The acceptable frequency tolerance is equal to the acceptable phase tolerance in fractional cycles divided by the transmitted pulse length in seconds. Plus or minus 2.5 degrees is an acceptable phase variation for the 22.5 degree measurement necessary in the 8 vector phase multiplexed systems. The tolerance can be relaxed to plus or minus 3.0 degrees for a 45 degree measurement used in the 4 vector phase multiplexed system. As an example the acceptable frequency tolerance is plus or minus 1.0 cycles per second for a 4 vector, 13.33 millisecond system and plus or minus 2 cycles per second for the 8 vector, 3.33 millisecond system.

Phase Subcarrier Modulation

Each data subcarrier is phase modulated by associated binary data channels in the manner described below. Wherein "M" refers to mark, "S" refers to space and the numerals refer to the channel numbers associated with each subcarrier. The convention for amplitude modulation is also shown.

CHANNEL CODING	TRANSMITTED PHASE AS REFERENCED TO PREVIOUS PULSE IN DEGREES (NOTE 5)		
(Two Channels per Subcarrier, 4 Vector System)	*Reversed Sub-Channels By External Patching*		
M1 M2	*M1 M2*	*-45*	*(Acceptable*
M1 S2	*S1 M2*	*-315*	*Tolerance*
S1 S2	*S1 S2*	*-225*	*±5.0 degrees)*
S1 M2	*M1 S2*	*-135*	

Note 5 : Minus sign indicates the phase has been retarded from reference. +360 degrees may be algebraically added to the phases to arrive at a positive set of phases.

The mark or space for the 3rd channel is encoded as differential. A change in amplitude from the previous stored pulse is coded as a mark "M."

The above frequency and phase tolerances in general are satisfactory for present equipment and system requirements. Although, these tolerances can be greater or less for any specific system requirement.

The subcarrier phase modulation corresponds to Figure 8-1.

Format standardization is not too critical in that only certain portions of message structures need to be standardized to permit recognition of address and supervisory signals.

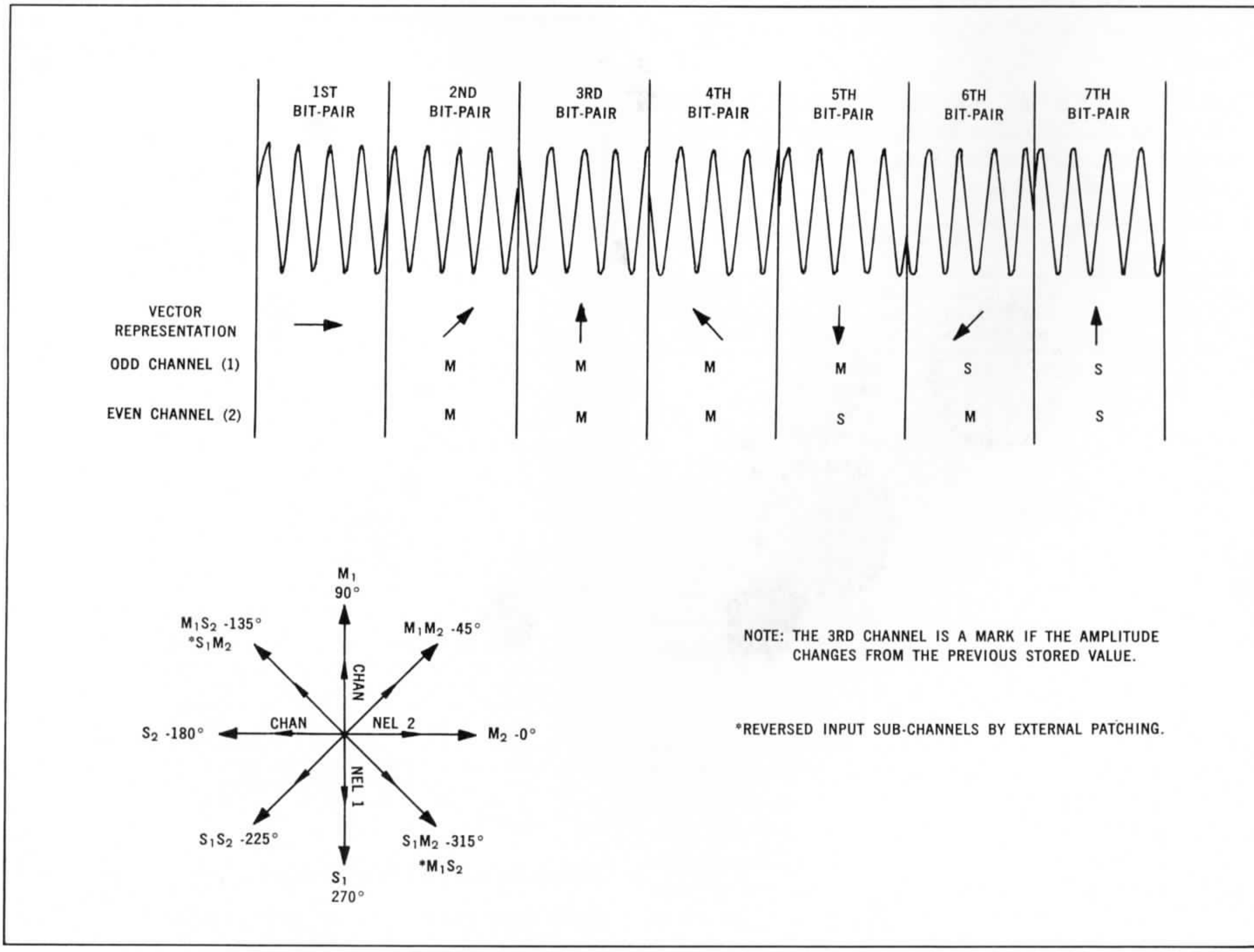


Figure 8-1. Typical Data Sequence Showing Relative Phase of Succeeding Pulses.