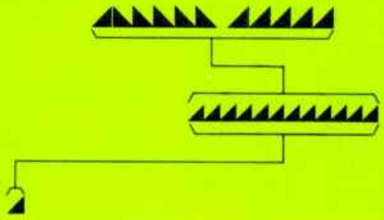
GTE LENKURT

DEMODULATOR

SEPTEMBER 1973

FDM Modulation Plans and Polylithic Crystal Filters

As developments in multiplex technology produce larger and more flexible systems, new modulation plans bring greater economic benefits to telecommunications equipment users.



Multiplexing is the means by which several circuits may be combined for transmission over a common transmission path. Modulation is a step in the process by which multiplexing is accomplished. While various types of modulation are possible, there are only two basic multiplexing techniques in common use – FDM (frequency division multiplexing) and TDM (time division multiplexing).

Frequency division multiplexing is a method of multiplexing in which two or more voice-frequency signals are translated to separate frequency bands by modulation processes so that they can then be combined and transmitted over a single medium. The two types of modulation used in FDM are amplitude modulation (AM) and frequency modulation (FM). This discussion centers around amplitude-modulated FDM systems.

Amplitude modulation is the process by which a carrier of constant frequency and constant amplitude is mixed with another signal, which is usually variable in both frequency and amplitude, and which is commonly called the modulating frequency. The amplitude of the carrier frequency is varied above and below its normal value in accordance with the modulating frequency (see Figure 1). The resultant of this process is three distinct and separate frequency components: (1) The original carrier-frequency component, (2) the sum of the carrier and the modulating frequency, and (3) the difference between the carrier and the modulating frequency. With a complex modulating wave, such as speech, the side frequencies above and below the carrier each consist of a band of frequencies. These two bands are called the upper and lower sidebands, and each contains the same information.

The sidebands obtained from a complex wave each have the same bandwidth as the original modulating wave; each contains the same intelligence; and, the frequencies in the upper sideband have the same relative relationship as the modulating wave; those in the lower sideband have an inverse relationship. Power distribution in the sidebands is directly related to the distribution of power in the modulating wave. As a result of amplitude modulation, the frequency band of the modulating wave is translated to a different position in the frequency spectrum. If both sidebands and the carrier are transmitted, the technique is called double-sideband transmitted-

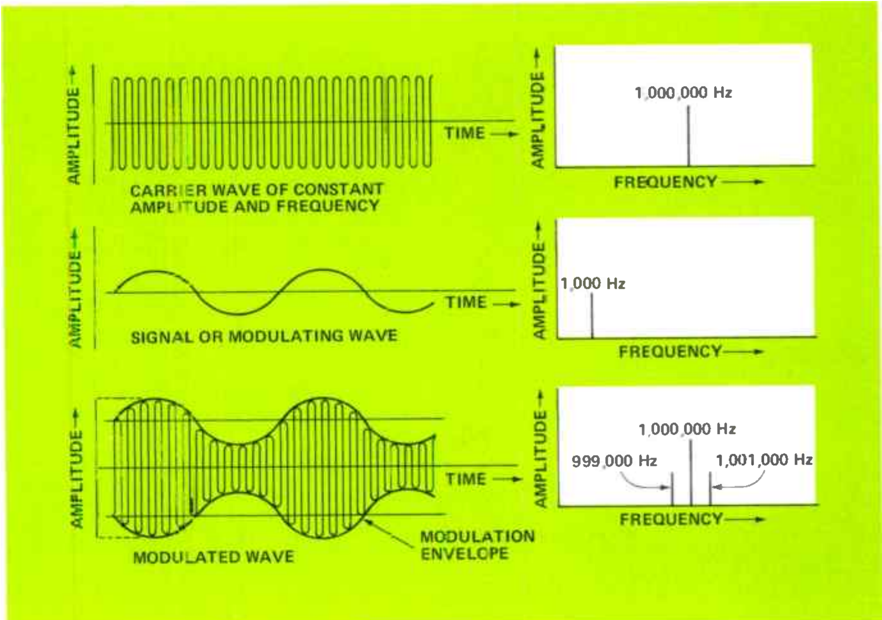


Figure 1. The resultant of amplitude modulation contains the carrier frequency component and the sum and difference of the carrier and modulating frequency.

carrier modulation (DSBTC). If the carrier is not transmitted, the technique is called double-sideband suppressed carrier (DSBSC).

Single-Sideband Suppressed Carrier

The most widely used modulation technique in frequency-division multiplexing is single-sideband suppressed carrier (SSBSC). Since the two sidebands produced during modulation contain identical information, only one is required to transmit the signal information. A balanced modulator is used to suppress the carrier, leaving only the two sidebands. Sideband suppression is accomplished by applying the modulated signal to a filter which passes only one of the sidebands while effectively attenuating the other. The bandwidth of the remaining sideband is now approximately equal to the original voice-frequency signal (about 3100 Hz).

Interconnection

When two carrier systems of different manufacture are interconnected within systems, signals at the interface point must satisfy the requirements of the receiving system. To this extent, it has been necessary to adopt standard modulation plans which allow different carrier and multiplex systems to be interconnected directly at line or baseband frequencies or at some intermediate stage of modulation. This allows groups of channels to be transferred between systems without the need for extra equipment and unnecessary modulation steps. Each type of carrier and multiplex system employs some type of modulation scheme to shift

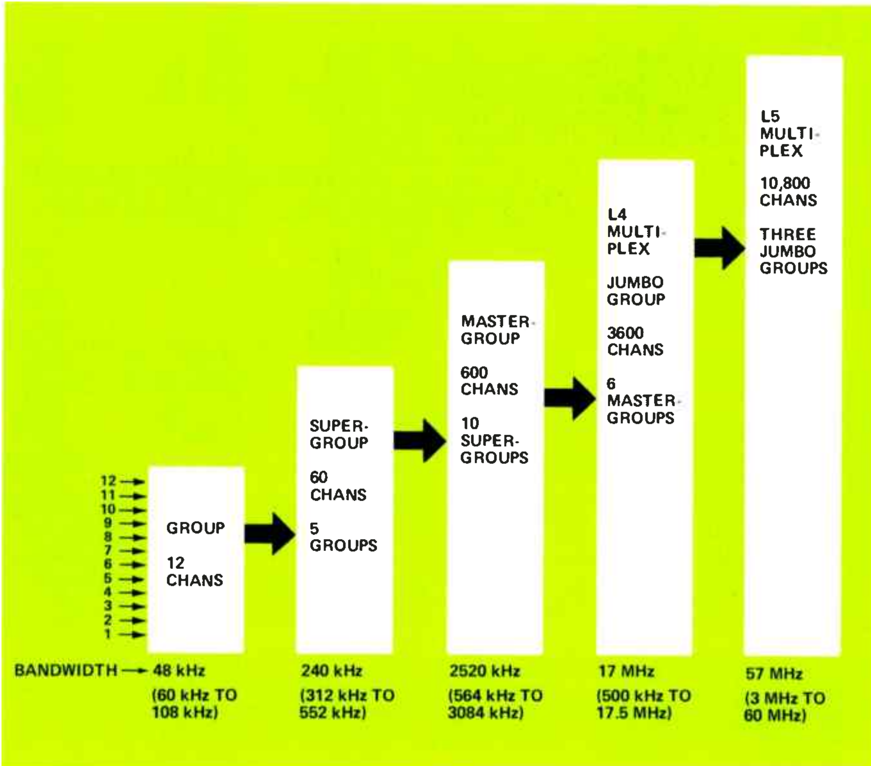


Figure 2. The hierarchy of FDM terminals.

the voice-frequency signals received from user equipment to a suitable line or baseband frequency range. This requires standardization of spacings of channel frequencies. In the 1930's the Bell System decided on a uniform channel spacing of 4 kHz; this requirement continues to be used today.

In SSBSC multiplex systems, voice channels are spaced at 4-kHz intervals to accommodate the voice frequencies in the range from about 300 Hz to 3400 Hz. Guardbands are provided between channels to prevent inter-channel crosstalk, and are also inserted between the various levels of the FDM hierarchy. To process a wider band of frequencies, such as required for video signals, multiplex systems often provide a means for combining groups of voice channels to acquire a single wideband channel.

FDM Terminals

Figure 2 shows the hierarchy of FDM terminals. The standard channel group contains 12 voice channels and extends in frequency from 60 kHz to 108 kHz (48-kHz bandwidth), with each channel occupying a band that is 4 kHz wide. The 12-channel group is widely accepted as the basic building block for long-haul carrier and multiplex systems. A standard 60-channel supergroup consists of five 12-channel groups, each at 60 kHz to 108 kHz.

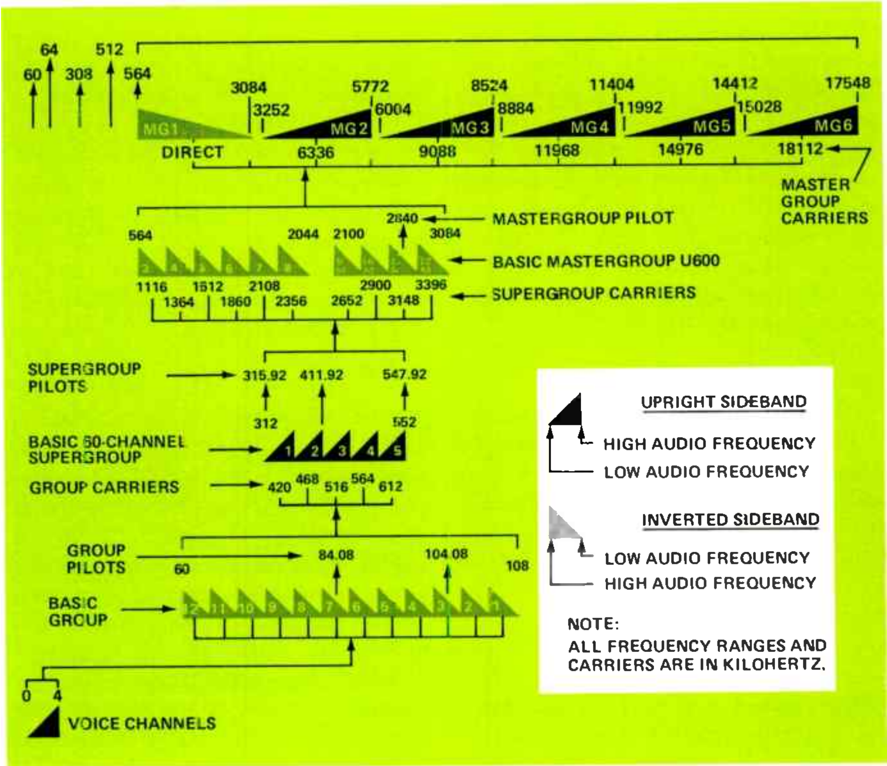


Figure 3. Conventional FDM frequency allocation and modulation.

The position of a 60 channel supergroup lies in the frequency spectrum of 312 kHz to 552 kHz. Ten supergroups make up a mastergroup which contains 600 channels, has a bandwidth of 2520 kHz, and lies in the 564 kHz to 3084 kHz region. The Bell System's L4 coaxial cable multiplex system assembles six mastergroups into a "jumbo" group to provide 3600 channels between 500 kHz and 17.5 MHz. And, in the future, three jumbo groups will be combined to provide 10,800 channels in the frequency spectrum between 3 MHz and 60 MHz.

An example of a conventional frequency allocation and modulation plan for a multiplex system is shown in Figure 3. In the first modulation stage, each voice frequency input signal modulates one of 12 channel carrier frequencies. The lower sideband signals are selected to provide the standard 60-kHz to 108-kHz, 12-channel group. In the second modulation stage, five 12-channel groups each modulate a separate group carrier frequency to produce a standard 60-channel supergroup with a frequency range of 312 kHz to 552 kHz. Ten of these supergroups form a 600-channel mastergroup. In the third stage of modulation, ten supergroups each modulate a separate supergroup carrier, resulting in line frequencies ranging from 564 kHz to 3084 kHz. Adherence to standard frequency allocation and modulation plans makes it possible to directly interconnect 12-channel, 60-channel, and higher-order channel groups of various carrier and multiplex systems, without having to first demodulate the signals down to the voice frequency range. With the large number of frequencies present in modern multiplex systems, frequency stability is a major concern to the user of telecommunications equipment.

Frequency Stability

The use of many individual carrier oscillators in a multiplex system would introduce a problem of frequency stability. Although frequency stability is often associated with the change in frequency of an oscillator over a period of time, the frequency stability of concern in a multiplex system is the net change in voice frequency that occurs between the sending end of the system and the receiving end. For voice communications via telephone systems, the permissable amount of frequency change and, indirectly, the required frequency stability, is related to the change which may occur without it being discernible to the ear. End-to-end frequency change of ±3 to ±5 Hz is satisfactory for voice communications. However, frequency stability is more critical in multiplex systems carrying telegraph and high-speed data. For this reason, most standards for frequency change in multiplex systems specify that the difference in frequency from one end of the system to the other shall not exceed 1 or 2 Hz.

Pilot Frequencies

Pilot frequencies are auxiliary signals employed in multiplex systems for such functions as level regulation, frequency synchronization, alarm systems, and maintenance monitoring. The transmit line levels at multiplex terminals and at repeaters must be maintained within close tolerances. Line noise and crosstalk from adjacent systems increase if the level is too low, while too high a level causes overloading, which can result in intermodulation distortion and crosstalk into other systems. Regulating pilots are used to operate compensating devices throughout the multiplex system in order to control line levels.

A line pilot is often used for end-to-end frequency synchronization. This is especially important in SSBSC systems, where the demodulating carrier frequencies must be reinserted at the receiving terminal. Frequency synchronization is accomplished by phase locking the master oscillator at a "slave" terminal to the line pilot frequency transmitted by the "master" terminal. Therefore, if the master oscillator frequency (thus, the line pilot frequency) at the transmit terminal changes, the synchronized oscillator frequency at the receive terminal will change a like amount.

The frequency of the pilots and the number required in each multiplex system depend mainly on the particular frequency allocation and modulation plan, and on any special needs of the system. Pilots are normally transmitted at a level 10 to 20 dB below the system test-tone level.

New Modulation Plans

Advances in filter technology have been a great influence in reducing the price and size of today's multiplex systems. Traditional LC filters have relatively low Q and have the disadvantage of limiting the passband due to their sloping sides. Although attenuation equalizers are used to "flatten" the passband of these filters, they add

Figure 4. Typical passband of a polylithic crystal filter.

bulk and expense to the filter. The polylithic crystal filter, now being used in increasing proportions in more advanced systems, is a high Q device which provides a passband with steep sides and almost-square corners as shown in Figure 4. (See the November and December, 1970 issues of the Demodulator for a discussion of polylithic crystal filters.) The polylithic crystal filters manufactured by GTE Lenkurt operate most efficiently around 8 MHz, and it is within this frequency range that the latest modulation plans have been designed for new multiplex equipment such as the GTE Lenkurt 36A and 46A3. Both of these systems incorporate the crystal filter in their design although each system is intended for a different purpose. The 36A is a specialized direct-to-line system intended for the industrial user, while the 46A3 is a high-density toll-grade system designed for voice and data transmission over microwave radio or coaxial cable facilities. Both 36A and 46A3 systems may be used in combination, with the 36A occupying the lower frequency spectrum and the higher-density 46A3 occupying the spectrum above the 36A position.

The crystal filter used with the 46A3 allows the initial modulation and subsequent filtering to select the single sideband (upper) of the twelve 4-kHz channels to take place at 8140 kHz to 8188 kHz (48 kHz wide). The 8140-kHz to 8188-kHz primary group is then modulated with a single carrier, 8248 kHz for example, to place it in its standard group position (the 60-kHz to 108-kHz slot). Using this same technique, but different primary group modulating frequencies, DTL (direct-to-line) modulation can be accomplished.

Direct-To-Line Modulation

DTL modulation allows any 12-channel primary group to be positioned in any one of eleven desired 12-channel frequency allocations. This is done by mixing the 12-channel primary group (8140 kHz to 8188 kHz) with any of the eleven available carrier frequencies, as shown in the DTL portion of Figure 5. Use of the DTL technique allows the formation of a maximum of 132 channels that

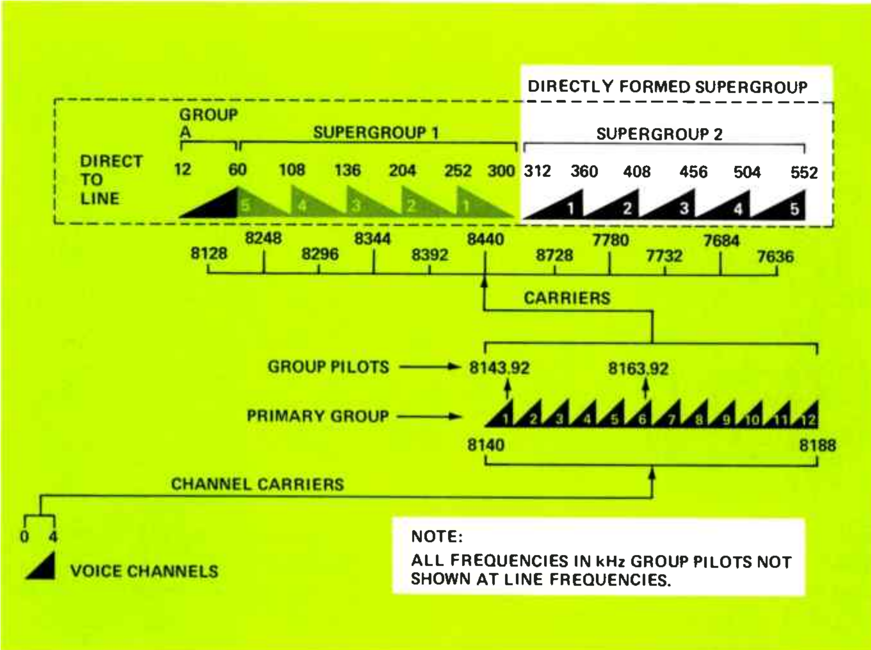


Figure 5. Direct-to-line and directly-formed supergroup modulation plans.

can be placed directly on a high frequency line in the band of 12 kHz to 552 kHz, without any other modulation required. This eliminates the group and supergroup equipment required in conventional modulation plans. DTL provides the correct sideband orientation to be compatible with conventional systems at the other end of a line and also eliminates one modulation step which results in better overall system performance. All frequencies are derived from a master-frequency source of 8192 kHz, which eliminates the possibility of frequency shifts that could cause channels to overlap and interfere with each other. The necessary carrier frequencies are obtained from the master source by binary chains of division and multiplication. DTL equipment offers the telephone, industrial, special service common carrier, and government users a low-cost, low-density, toll-grade carrier, which meets CCITT and U.S. standards. Also, the Group A portion of the DTL channel equipment conforms to the 12-kHz to 60-kHz channel group most often required by satellite communications systems. DTL equipment is designed for use in a microwave transmission system such as with the GTE Lenkurt 78F2 radio in the 2-GHz band. A block diagram of a typical DTL terminal is shown in Figure 6. For larger systems, the DFSG (directly formed supergroup) may be used.

Directly-Formed Supergroup

The DFSG forms a line spectrum of 312 kHz to 552 kHz, and can be used with either microwave radio or coaxial cable systems. DFSG equipment elimi-

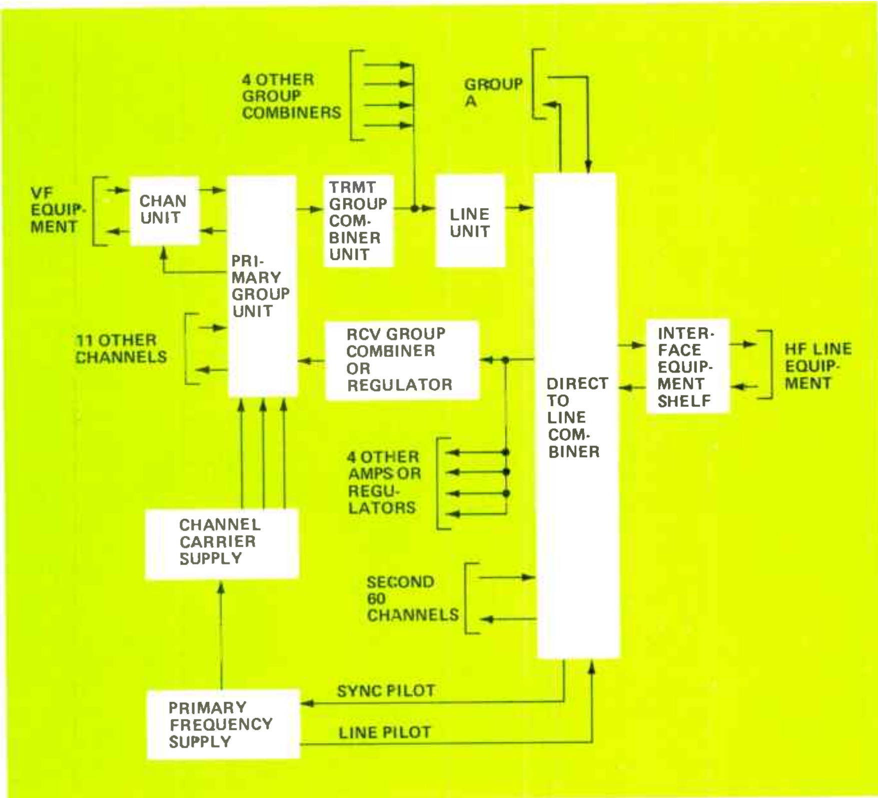


Figure 6. Typical DTL terminal configuration.

nates group shelves and group carrier supplies, and is designed for applications where a large number of channels is to be terminated at a single location. The DFSG can be fed to a basic supergroup shelf for a 600-channel system, which can in turn be translated to mastergroup equipment for a total of 1200 channels. Further developments will expand the 1200-channel capacity to 1800, 2400, and ultimately to a jumbo group of 3600 channels, and to combinations of jumbo groups. The modulation plan of the directly formed supergroup is shown in Figure 5. Twelve 0-4 kHz channels are arranged to form a primary group at 8140 kHz to 8188 kHz. Five primary groups are each modulated with a different carrier to form a basic 60-channel supergroup at 312 kHz to 552 kHz. This basic supergroup is formed directly with this one modulation step. in contrast to the conventional method of modulating five 60-kHz to 108-kHz basic groups with carrier frequencies to form a basic 60-channel supergroup.

The process of carrier frequency derivation requires that the 8192 kHz from the master frequency generator be mixed with a 4-kHz pulse, which will provide the 4-kHz frequency multiples necessary for the line fre-

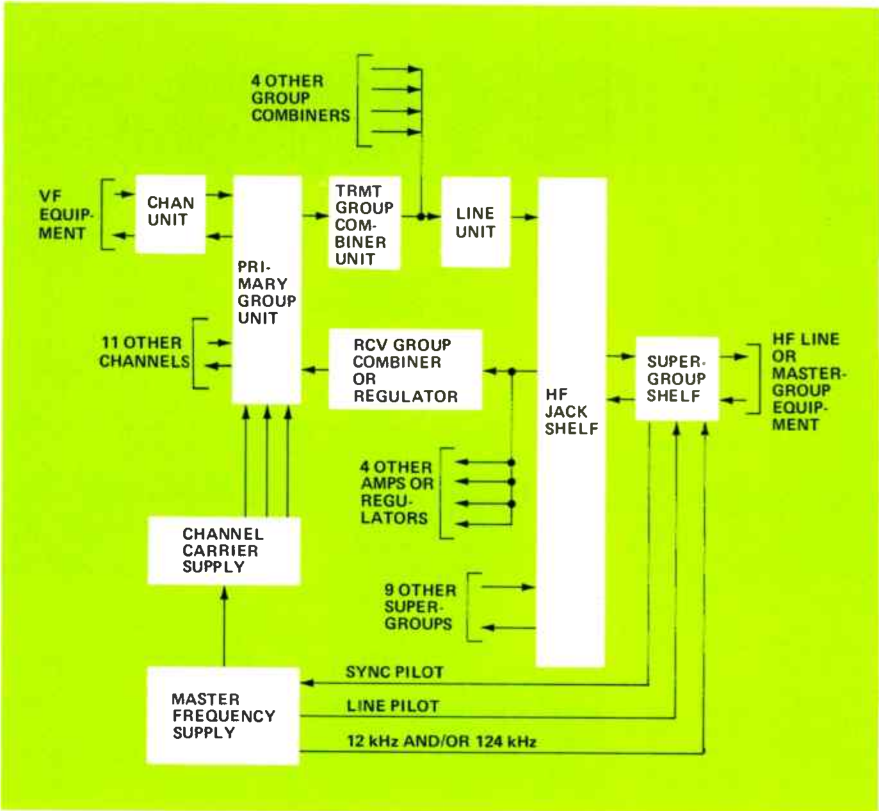


Figure 7. Typical DFSG terminal configuration.

quencies. The result of the mixing process produces a whole spectrum of frequencies at 4-kHz increments above and below 8192 kHz. This whole spectrum is fed into a narrow band crystal filter tuned to a particular frequency, and only that frequency will be passed. Here the polylithic crystal filter is used in a different application – as a narrow band pilot or carrier pick-off filter rather than a sideband bandpass filter.

Line pilots at any of five frequencies – 60 kHz, 64 kHz, 308 kHz, 512 kHz, or 564 kHz, may be used for frequency synchronization. The line pilot is used to phase lock the master frequency oscillator (8192 kHz), thereby preventing frequency shift from end-to-end. Figure 7 shows a block diagram of a typical DFSG terminal.

DTL and DFSG offer the advantage of flexibility for the high-density user. By proper system planning, a low-cost, initial system of DTL equipment may be installed and later expanded with DFSG or conventional channel equipment. Expansion into mastergroups is accomplished with conventional supergroup and mastergroup equipment. If 60 kHz to 108 kHz access is required within a given DFSG multiplex system, certain supergroups may be equipped with conventional group equipment, thus mixing both DFSG and conventional equipments within the same system.

The elimination of group equipment through the use of DFSG equipment offers the user advantages over the use of conventional modulation steps. The first obvious advantage is a reduction in equipment costs – approximately 7% to 13%. Other advantages include, less equipment to install and maintain, increased reliability by reducing the amount of equipment required and improved noise performance for total systems.

DTL and DFSG offer new applications of GTE Lenkurt 46A3 and similar equipment. The direct-to-line equipment can meet the needs of the low-density systems, and directly-formed-supergroup equipment promises a savings in equipment and installation costs for high-density systems.

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