Sideband Lock SCPDM Modem for Simultaneous Voice and Data Communications

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Summary. - A modem technique for simultaneous transmission of voice and digital data is presented. The salient feature of this technique is the use of quadrature carrier multiplexing of a suppressed clock pulse duration modulation (SCPDM) signal with a biphase NRZ data stream. A novel method for separating the voice and data components at the receiver is described.

Data bit error rate and voice intelligibility test results are presented and discussed.

Introduction. - The most efficient operation of a satellite repeater is obtained with constant envelope signals.

Hard limiting or equivalent techniques are, therefore, commonly used to provide a constant envelope output signal of a satellite repeater. The modulation format to be used with these repeaters must then be such that the hard limiting does not affect the signal structure. Furthermore, when more than one channel of information is used with a single carrier, the multiplexing of the signals must be such that the crosstalk between the channels is not generated by passage through a hard limiting repeater. Quadriphase signals are thus widely used for multiplexing two simultaneous baseband signals.

The demodulation of the quadriphase signals, however, is a rather difficult task, particularly if the two signal components carry equal amount of carrier power. However, if at least one of the signals has a unique spectral characteristic reliable channel separation can be obtained. The modem implementation described in this paper illustrates how quadriphase multiplexing of voice and digital data can be implemented and the separation of the two signals can be realized by using a unique spectral characteristic of one of the signals.

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Specifically, to provide for multiplexing and separation of the voice channels two proven techniques, namely, suppressed clock pulse duration modulation (SCPDM) for voice transmission[1] and differentially encoded phase shift keying (DPSK) for data transmission are used. Both of these modulation techniques result in constant envelope outputs and therefore, either singly or in combination, can be handled by an amplitude limiting satellite repeater. Furthermore, utilization of SCPDM provides a voice communication link with a feature of graceful degradation at low C/N_o thus eliminating the precipitous loss in output signal quality which is typical of even narrowband FM systems operating below their specified threshold.

This paper describes a modem equipment built to provide simultaneous transmission of voice and digital data. The modem can also be operated in either data only or voice only modes. The data rate is selectable and is either 1200 bps or 2400 bps. The voice channel bandwidth is from 300 Hz to 3500 Hz and the SCPDM is used for this channel.

Overall Description of the Modem. - For transmission of voice only, the SCPDM processor's output signal, which consists of a constant amplitude square wave with the transitions carrying the voice information, is applied to a balanced modulator, thus resulting in a biphase modulated suppressed carrier output signal. Similarly, when data only is transmitted, the resulting output is also a biphase modulated suppressed carrier. However, when voice and data are transmitted simultaneously, the two biphase modulated carriers are combined in quadrature thus resulting in a suppressed carrier, quadriphase modulated output. Because the two biphase modulated signals are derived from the same carrier source and are combined with equal weighing of each component, the resulting quadriphase modulated carrier provides for an even power division between voice and data channels and it also meets the requirement of a single carrier transmission.

At the demodulator end the rather tricky task of separating the voice and data carrying components of the composite quadriphase modulated carrier is performed by a special sideband-lock demodulator which seeks out and locks onto the predominant half-clock spectral line of the SCPDM signal. Once such lock is established, the demodulator tracks the phase of the voice-carrying component of the composite carrier and its output consists of raw SCPDM data which subsequently is processed to recover the voice information. The data stream is recovered by an auxiliary demodulator which is supplied by a carrier whose phase is in quadrature with the phase of the tracked voice-modulated carrier. In this manner the desired orthogonal demodulation and separation of the SCPDM voice and data streams is accomplished.

When voice only is being transmitted, the sideband-lock demodulator is still used, except that there is only one carrier at the demodulator input. However, since the demodulator tracks the half-clock SCPDM line, the recovery of this clock is automatically provided by the demodulator. For recovery of data only, the demodulator configuration is changed to the conventional Costas loop, a single carrier is tracked and the data, as well as the data clock, are recovered in a conventional manner.

Modulator Unit. - The modulator unit accepts the incoming baseband voice and/or data signals and after appropriate processing superimposes these signals on a 70 MHz modem output carrier. Figure 1 shows the functional block diagram of the modulator unit.

The Audio Processor accepts either a low level, low impedance microphone input (M) or a high level, high impedance recorder input (R) and provides the pre-emphasis and compression of the input audio signals. Subsequently, the compressed and pre-emphasized audio signal is applied to the SCPDM modulator where the analog audio signal is converted into a SCPDM signal. The clock frequency for SCPDM encoding is 9.6 KHz. It is derived by counting down the 38.4 KHz clock oscillator signal.

The Baseband Data Processor accepts either external data signals at 1200 or 2400 bps or it generates its own test data pattern sequence at either one of these two clock rates. Either the external data or the internally generated test data is then differentially encoded and supplied to the RF modulator unit. The clocks for the 1200 and 2400 bps operation are derived by counting down from a 38.4 KHz signal supplied by the clock oscillator. These stable clock signals are available at the modulator output for use with external data sources.

The RF Modulator accepts a 70 MHz carrier signal developed by a temperature compensated Oscillator unit. As shown in Figure 2, the 70 MHz signal is split into two equal power components 90° out of phase with each other. During simultaneous transmission of voice and data each of the components is biphase modulated by its respective baseband signal. Balanced modulator BM_1 handles the SCPDM voice signal and balanced modulator BM_2 handles the data. The two components are then recombined to form a single 70 MHz carrier quadriphase modulated signal. When only data or voice is transmitted the RF Modulator Board provides only a biphase modulated 70 MHz carrier.

For all modes the 70 MHz output of the modulator is a nominal 0 dBm into a 50 ohm load. The constant total output power level is achieved by supplying identical baseband signals, i.e., SCPDM or data, to both BM_1 and BM_2, thus forming a biphase signal out of two quadriphase components when voice only or data only mode operation is selected.

Demodulator Unit. - The functional block diagram of the Demodulator unit is shown in Figure 3.

The input to the demodulator is the 70 MHz signal whose nominal level is 0 dBm, varying from +10 dBm to -20 dBm. This signal is applied to the receiver front end where it is filtered, gain controlled, amplified and translated to a 2 MHz IF frequency. Noncoherent AGC is used in this unit. The local oscillator frequency is 72 MHz which is derived in the X9 multiplier from the 8 MHz VCO frequency. The 2 MHz IF signal is supplied to the synchronous demodulator.

Frequency search of the local 72 MHz signal is derived by multiplying the 8 MHz VCO by a factor of nine while the fundamental, 8 MHz VCO signal is swept around its center value. When the receiver is within the capture range of the synchronous demodulator the carrier lock detector supplies the necessary signals for stopping the search to the frequency search and carrier track unit. Coherent carrier tracking of the incoming signal commences upon the termination of the frequency search.

The synchronous demodulator performs the important function of coherent tracking of either the biphase (voice only or data only case) or the quadriphase (voice plus data case) modulated carrier as well as the function of recovering and separating (in case of voice plus data) the SCPDM and the differentially encoded data streams. The carrier tracking error is derived in this unit and is supplied to the temperature compensated voltage controlled oscillator from which all the local oscillator and demodulation CW signals are derived.

In the data only mode the demodulator is configured as a conventional Costas loop. In the voice and voice plus data modes the demodulator is configured as a sideband-lock demodulator which tracks the suppressed carrier by locking onto the 4.8 KHz SCPDM sidebands which are always present at sufficient level to provide the reliable acquisition. The sideband-lock mode is particularly suited to the simultaneous reception of voice plus data because it provides for unique identification of the data and voice quadrature components. The recovered voice and data baseband signals are applied to their respective demodulators.

The raw SCPDM signal developed by the synchronous demodulator is supplied to the SCPDM voice demodulator. Here the digital SCPDM modulation is converted to an analog voice signal which is then made available to a high impedance tape recorder (R) and also to a balanced 600 ohm jack for headset (H) monitoring.

The raw baseband data signal developed by the synchronous demodulator is applied to the data demodulator where the data clock is recovered and the data is optimally processed by an integrate and dump circuit. Differential decoding is also performed by this unit. Thus the outputs of this unit are the processed data and the recovered 1200 or 2400 bps clock. For instrumentation purposes the errors in the data received are identified by the data error detector unit. The error detection is accomplished by comparing the incoming data with a replica of the data developed by the data test sequence generator which is a part of this unit. Located within the data error detector unit is also the circuitry for buffering and linearizing the signal supplied to a C/N_o meter which can be located on the front panel of the C/N_o Test Set.

Demodulator Analysis. - In the voice plus data mode the separation of the SCPDM carrier component from the composite quadriphase modulated carrier is performed by the sideband-lock demodulator which extracts the voice-carrying component of the composite signal by locking onto the predominant sideband lines characteristic of the SCPDM signal. This section presents a simplified analysis of such demodulator.

To simplify the analysis let us assume that the 4.8 KHz half-clock SCPDM line is a sinewave which balance-modulates the voice carrying component of the composite carrier. Thus, the spectrum at the input to the demodulator will be, in the absence of voice modulation, similar to one shown in Figure 4.

The equation describing this waveform in time domain is then:

$$E_{in} = \cos\omega_{CL}t \cos\omega_{IF}t \qquad (1)$$

where ω_{CL} = half-clock frequency

ω_{IF} = IF frequency

Consider now the simplified block diagram of the sideband-lock demodulator shown in Figure 5. Also let us assume that frequency lock has occurred in both loops and only small phase tracking errors exist in each loop. These are:

α = sideband phase tracking error

and

β = carrier phase tracking error.

The output of balanced modulator BM, is then:

$$BM_1 \text{ Output} = \left[\cos\omega_{CL}t \cos\omega_{IF}t\right] \cdot \left[\sin\left(\omega_{CL}t + \alpha\right) \cos\left(\omega_{IF}t + \beta\right)\right] \qquad (2)$$

The second term in this equation is the result of multiplication in BM_3. Let us rearrange (2). Thus,

$$\text{BM}_1 \text{ Output} = \left[\sin\left(\omega_{CL}t + \alpha\right) \cos\omega_{CL}t\right] \left[\cos\left(\omega_{IF}t + \beta\right) \cos\omega_{IF}t\right] \quad (3)$$

Using known trigonometric identities let us examine Term 1 and Term 2 separately before forming their product.

$$\text{Term 1} = 1/2\left[\sin\left(\omega_{CL}t + \omega_{CL}t + \alpha\right) + \sin\left(\omega_{CL}t + \alpha - \omega_{CL}t\right)\right] \quad (4)$$

$$\cong 1/2 \sin\alpha$$

after we filter out the term which is close to twice the $\omega_{CL}t$ frequency.

Consider now Term 2:

$$\text{Term 2} = 1/2\left[\cos\left(\omega_{IF}t + \alpha + \omega_{IF}t\right) + \cos\left(\omega_{IF}t + \beta - \omega_{IF}t\right)\right] \quad (5)$$

$$\cong 1/2 \cos\beta$$

after we filter out the term which is close to twice the IF frequency.

Finally, we obtain for the output of BM_1:

$$\text{BM}_1 \text{ Output} \cong 1/4 \cos\beta \sin\alpha \quad (6)$$

Note that when the tracking errors are small in both loops we obtain:

$$\text{BM}_1 \text{ Output} \approx 1/4\ \alpha, \text{ since } \cos\beta \approx 1 \text{ and } \sin\alpha \approx \alpha \text{ for } \alpha << 1 \text{ radian} \quad (7)$$

Thus, we have shown that the control input to the sideband-tracking VCO is proportional to phase error of the sideband-tracking loop and is virtually independent of the phase error in the carrier tracking loop.

Using similar approach we can write the expression for the output of BM_2 as:

$$\text{BM}_2 \text{ Output} \approx 1/4\ \beta \quad (8)$$

Here again we have shown that the carrier-tracking loop is virtually independent from the sideband-tracking loop for small values of tracking errors in the latter loop. It is this virtual orthogonality of the two loops which is the key feature of the sideband-lock demodulator. For our particular application the sideband-lock demodulator will utilize the 4.8 KHz sideband lines predominant in the SCPDM modulated carrier. Such lock-up will uniquely identify the voice-carrying component of the quadriphase modulated composite carrier.

Carrier Search, Lock and Track Functions. - Figure 6 shows the block diagram interconnection of the demodulator subunits required for performing the carrier search, lock and track functions in either one of the three operating modes of the equipment. These three modes are: 1) voice-plus-data; 2) voice only and; 3) data only operation. For all of the modes, the demodulators local oscillator must search out the ±4 KHz frequency uncertainty of the incoming signal before the baseband data streams can be recovered by their respective demodulators. The nominal interval assigned for this search is one second.

The frequency search is performed by applying a sawtooth voltage to the input of the 8 MHz master VCO from which all the coherent LO and the demodulator references are derived. When the carrier lock is detected by the appropriate circuitry, the frequency search is terminated and tracking is initiated.

Consider first the operation in the voice-plus-data mode. As shown in Figure 6 in this mode the carrier quadrature, IF_Q and in-phase, IF_I, components of the 2 MHz LO are applied to coherent demodulators M_1 and M_4, respectively. Note that in the voice-plus-data mode, the in-phase carrier component is the one which carries the SCPDM voice information. The output of demodulators M_1 and M_4 are applied to bandpass filters BPF 1 and BPF 2. The bandpass of these filters is set at the 4.8 KHz suppressed clock PDM frequency and the 3 dB bandwidth of the filters is 50 Hz. Thus, as the swept LO is within 50 Hz of the true carrier frequency, the 4.8 KHz signal appears in both of these filters. The envelope-detected outputs $|I|_V$ and $|Q|_V$ of these filters are then added to form the $|I|_V + |Q|_V$ and the $|I|_V - |Q|_V$ terms. The former term, which is an envelope detected 4.8 KHz PDM half -clock is then applied to a threshold detector T_1.

When T_1 is exceeded, the frequency search is temporarily terminated. If crossing of T_1 is due to a true signal, the term $|I|_V - |Q|_V$ also goes high and one second after termination of search threshold T_2 is exceeded. Crossing of T_2 thus serves as an indication of lock. On the other hand, if crossing of T_1 is due to a false alarm, the frequency search remains after a 20 msec pause.

When both the carrier and the subcarrier locks are established, the carrier tracking error, CTE, is developed in the coherent demodulator M_3. In this case M_3 serves the same function as BM_2 of Figure 5 and the modulo-2 adder B acts as BM_4. Similarly, M_2 and modulo-2 adder A perform, respectively, the functions of BM_1 and BM_3 of Figure 5, thus providing a subcarrier tracking loop.

The baseband SCPDM information and the data streams are recovered by demodulators M_4 and M_1 respectively.

When in voice only mode, the search and track is performed in the same manner as in the voice-plus-data mode with the exception that no data appears at the output of M_1.

The data only mode the demodulators M_1 and M_4 perform the function of the in-phase and the quadrature phase detectors of the Costas loop respectively. The carrier lock test is performed by sensing the magnitude of the $|I|_D$ - $|Q|_D$ signal and by stopping the frequency search when this signal exceeds threshold T_1. If true lock occurs, the threshold T_2 is then exceeded and one second later the carrier sync is declared. For a false lock case the search is resumed after a 10 msec search interrupt period. When the Costas loop is tracking the carrier, the tracking error is generated by the balanced modulator M_4 and the data component is removed from this error by the analog multiplier. The baseband 1200 bps or 2400 bps data is demodulated by M_1 in the data only mode.

In all modes the one-sided noise bandwidth B_L of the carrier tracking loop is about 100 Hz.

Audio Processing. - The overall 3 dB bandwidth of the modem audio channel extends from 300 Hz to 3,500 Hz. The pre-emphasis network consisting of a two-pole 900 Hz carrier frequency roll-off is used at the modulator prior to voice compression. A matching de-emphasis network is used at the demodulator. The frequency characteristics of this network were chosen to approximate the roll-off characteristics of the human voice. However, it was determined experimentally on this modem development program, as well as on related SCPDM programs, that if at least one roll-off network is used in 500 Hz to 900 Hz region the addition of other networks has very little noticeable effect on the intelligibility. It was also determined that degree of voice clipping has little noticeable effect on speech intelligibility. The main purpose of clipping is thus to reduce the dynamic range of the signal applied to the SCPDM modulator.

Auxiliary Circuits. - For the data performance testing a built-in test pattern generator was used. This generator, is located within the modulator unit. The test sequence polynomial used is $X^{11} + X^2 + 1$ and test data can be generated at either the 1200 bps or 2400 bps rate. A corresponding test pattern detector is used at the demodulator unit. This test pattern detector generates a standard format pulse when a bit error is detected.

The demodulator also generates, in all modes, a signal which can be used to display a C/N_o reading on an external test set. The C/N_o display signal is linear within ±1 dB over the 50 to 37 dB-Hz range. The modulator/demodulator units and the C/N_o test set are shown in Figure 10.

Performance. - The bit error rate (BER) performance test results for the 1200 bps and the 2400 bps operation are shown in Figures 7 and 8, respectively. From this test data it can be seen that the BER performance of the modem is within one dB of the theoretical performance from the differentially encoded phase-shift keyed signal. These carriers also show the effect of the 3 dB power division between the data only and the voice-plus-data modes.

The voice intelligibility testing of the sideband-lock modem was done using Harvards phonetically-balanced (PB) 50-word lists[2]. The test tapes were made at various values of C/N_o and the intelligibility of the tape material was evaluated by the CBS Laboratories using a panel of trained listeners[3].

Figure 9 shows the results of this testing for both the voice only and the voice-plus-data modes. The curves show the effect of the 3 dB power division between the two modes. No significant degradation beyond the expected 3 dB due to power division is shown by the data. It must be also pointed out that because the lowest C/N_o test points were taken with female speakers the curves exhibit an apparent knee at lower C/N_o. This knee would, most likely, be less pronounced if the male speakers were used for all test points.

In all, however, the intelligibility results are consistent with test results obtained for similar modems operating in the SCPDM voice only mode.

Conclusion. - A modulation/demodulation equipment capable of simultaneous transmission of voice and data information was developed and tested. The salient feature of this equipment is the voice channel separation by means of sideband locking of the SCPDM half-clock line. Test results for data and voice intelligibility are within one dB of theoretically expected performance.

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References.

[1] L. Jacobson, R. Schoolcraft and P. Hooten, “Highly Efficient Voice Modulation for Low C/N_o Communications Channels with Hard Limiting Repeaters”, IEEE International Conference on Communications, Philadelphia, Pa. , June 19-21, 1972.

[2] J. N. Birch and N. Getzin, “Voice Coding and Intelligibility Testing for Satellite Based Air Traffic Control System”. Goddard Space Flight Center, April, 1971, Final Report.

[3] P. Milner, “Advantages of Using Experienced Listeners in Intelligibility Testing”, IEEE Transaction on Audio and Electroacoustics, Vol. AU-21, No. 3, June 1973. pp 161 to 165.

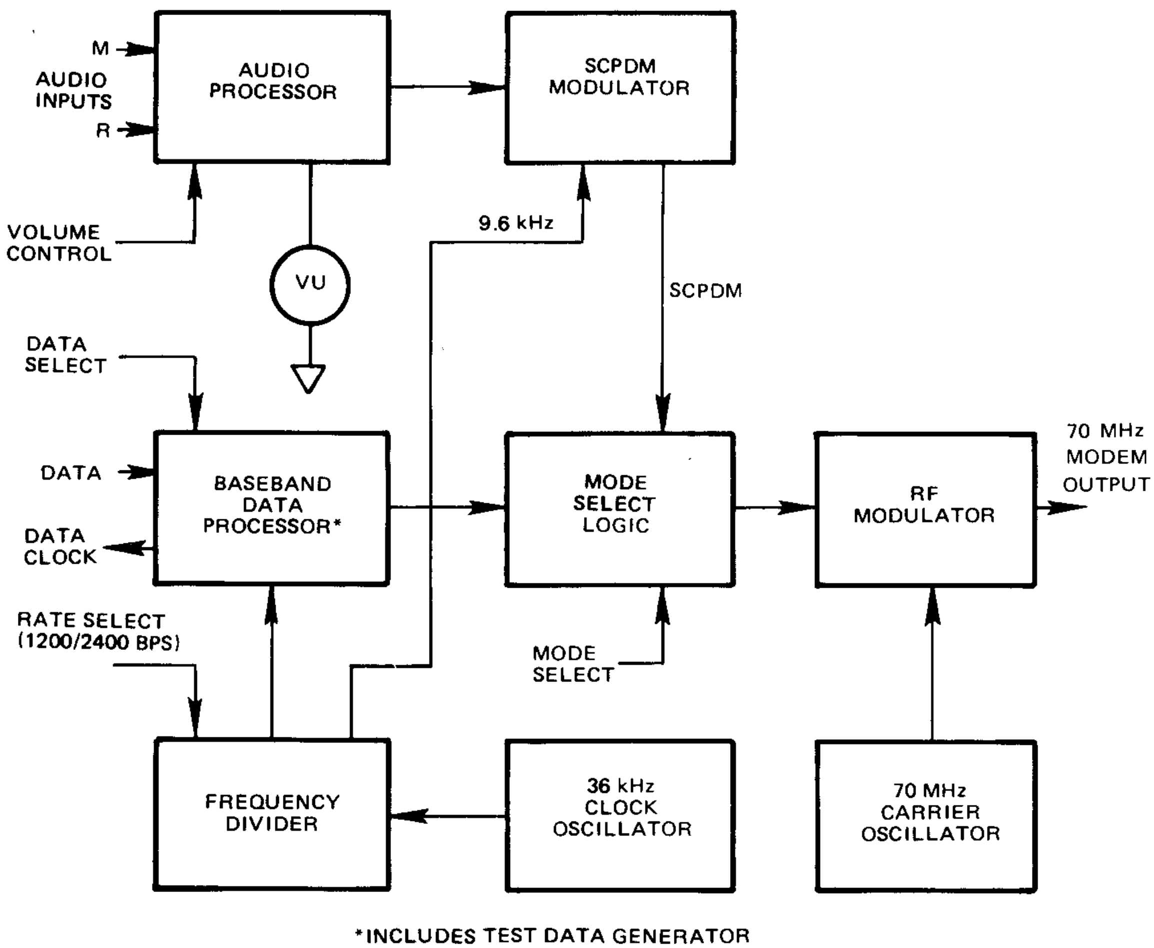

Fig. 1 - Modulator Unit Functional Block Diagram

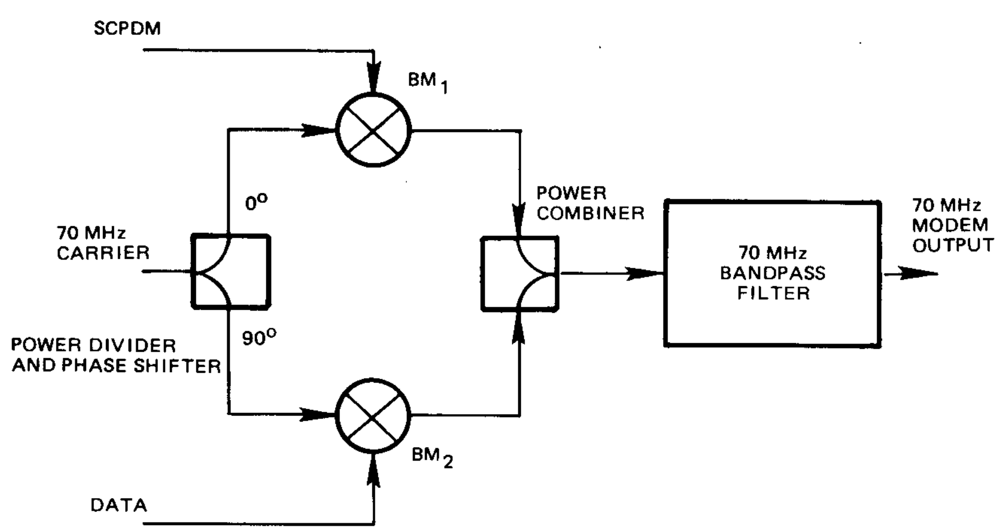

Fig. 2 - RF Modulator Block Diagram

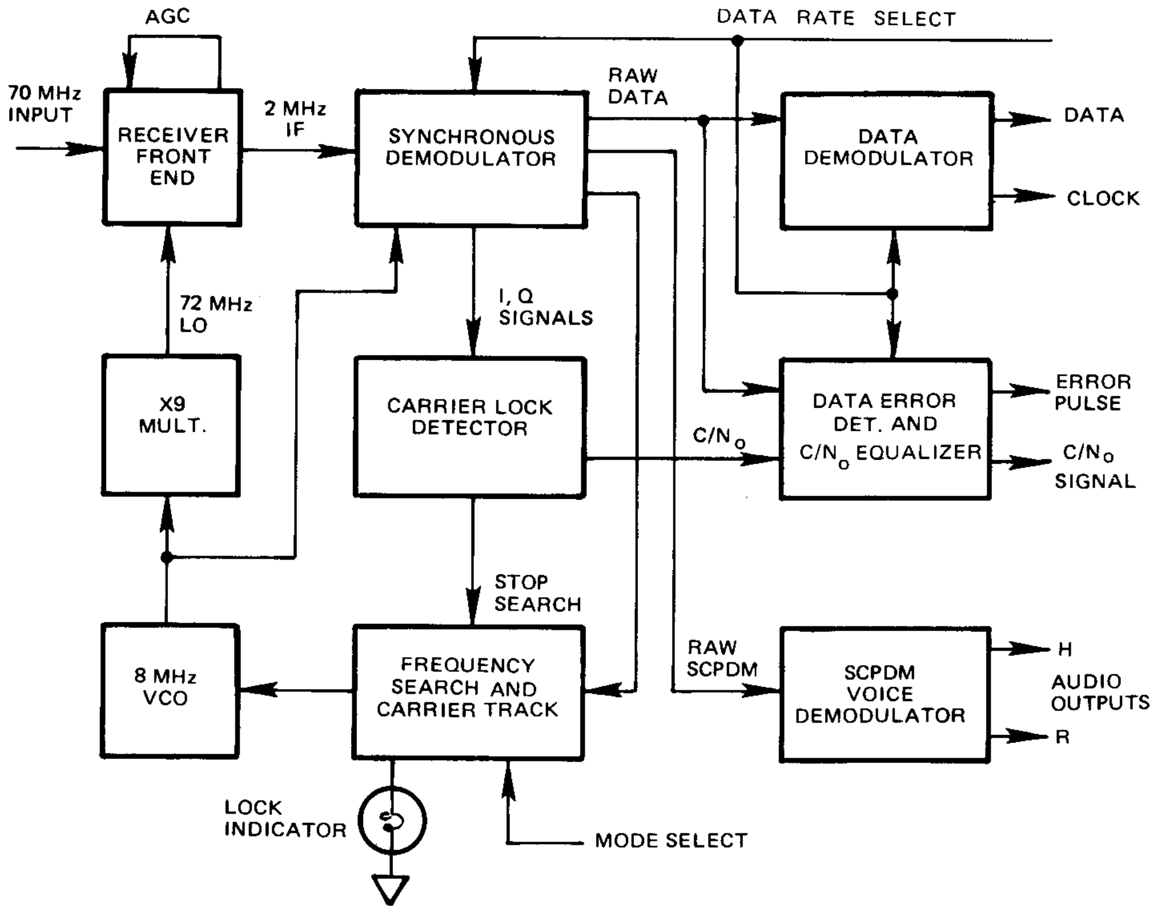

Fig. 3 - Demodulator Unit Functional Block Diagram

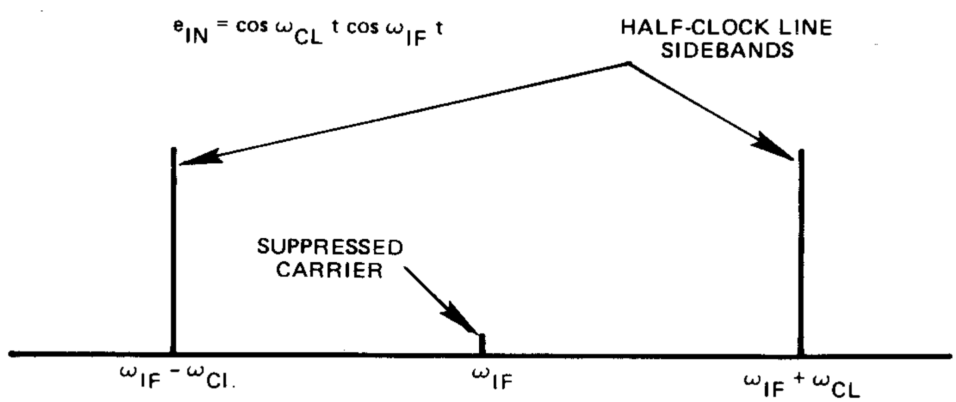

Fig. 4 - Simplified Spectrum and Assumed Input Signal

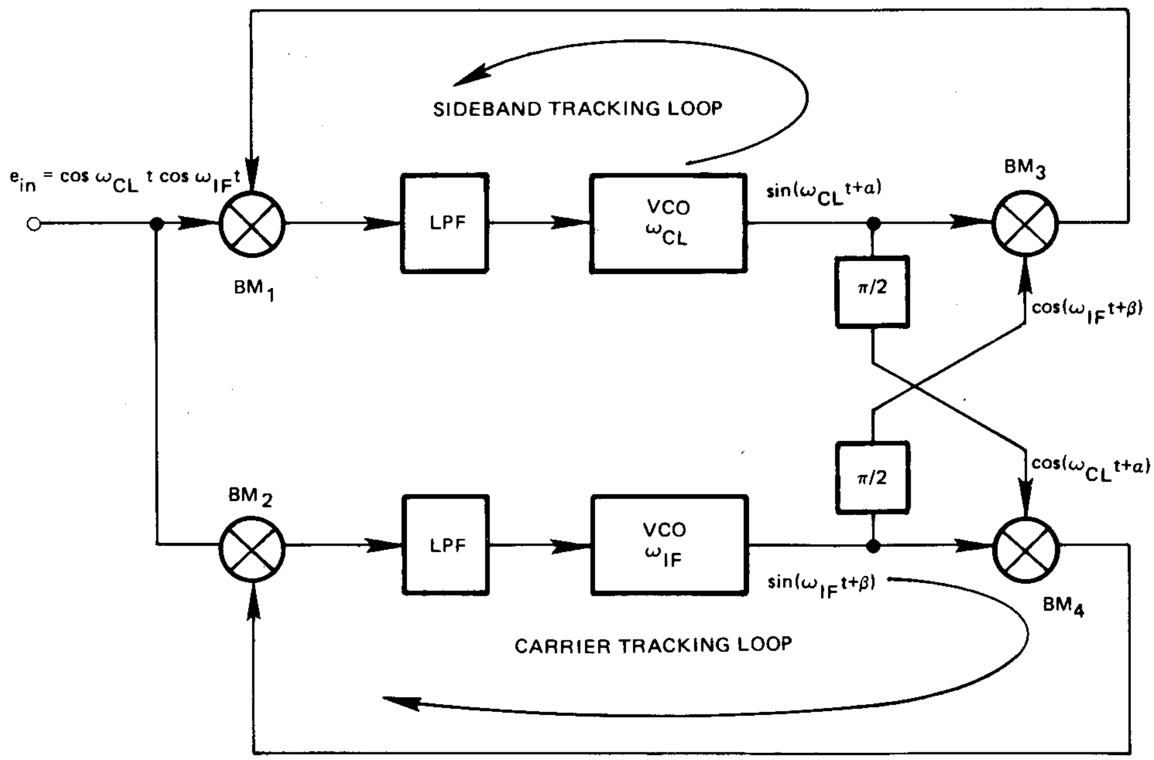

Fig. 5 - Sideband-Lock Demodulator Simplified Block Diagram

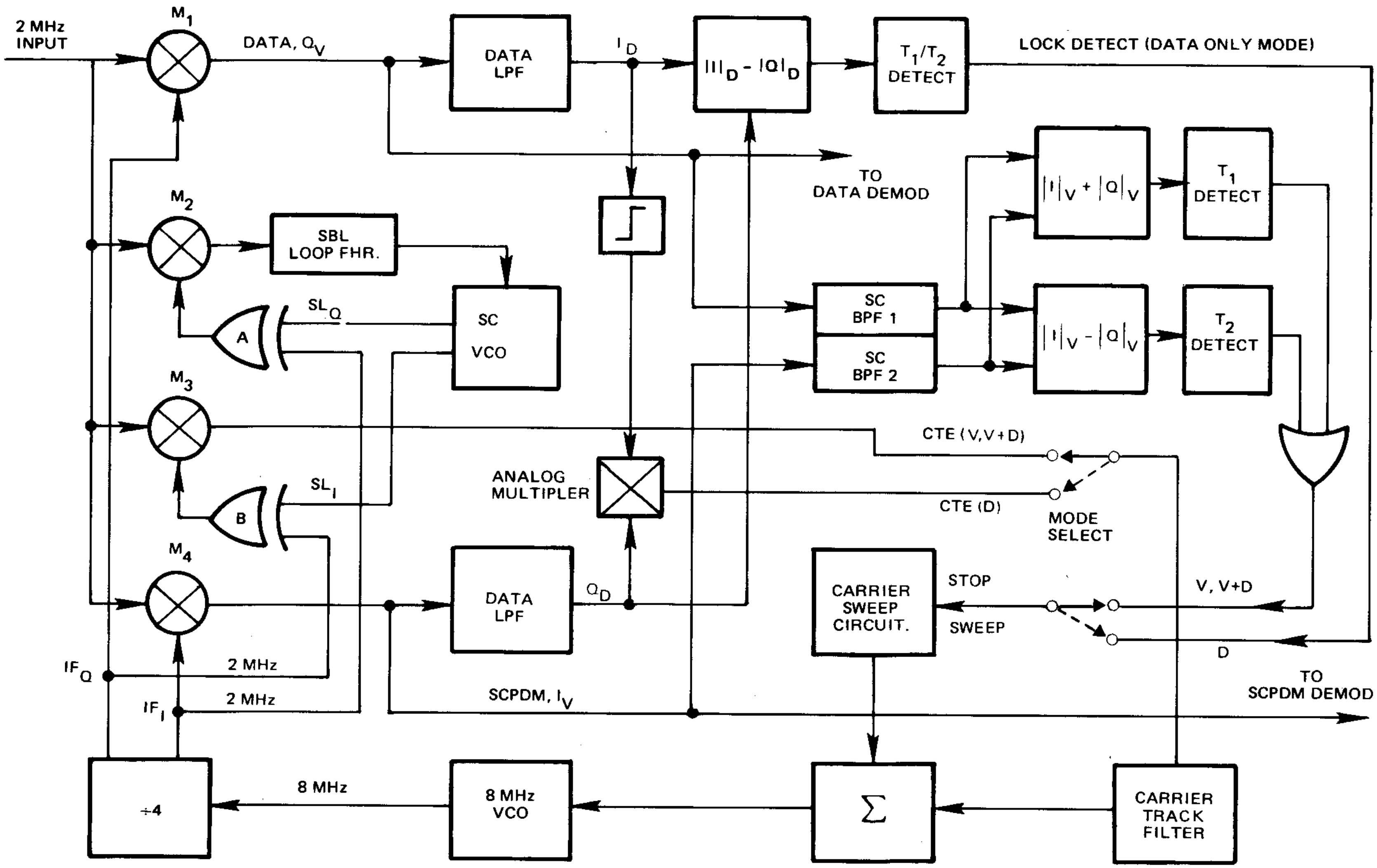

Fig. 6 - Carrier Search, Lock and Track Functions

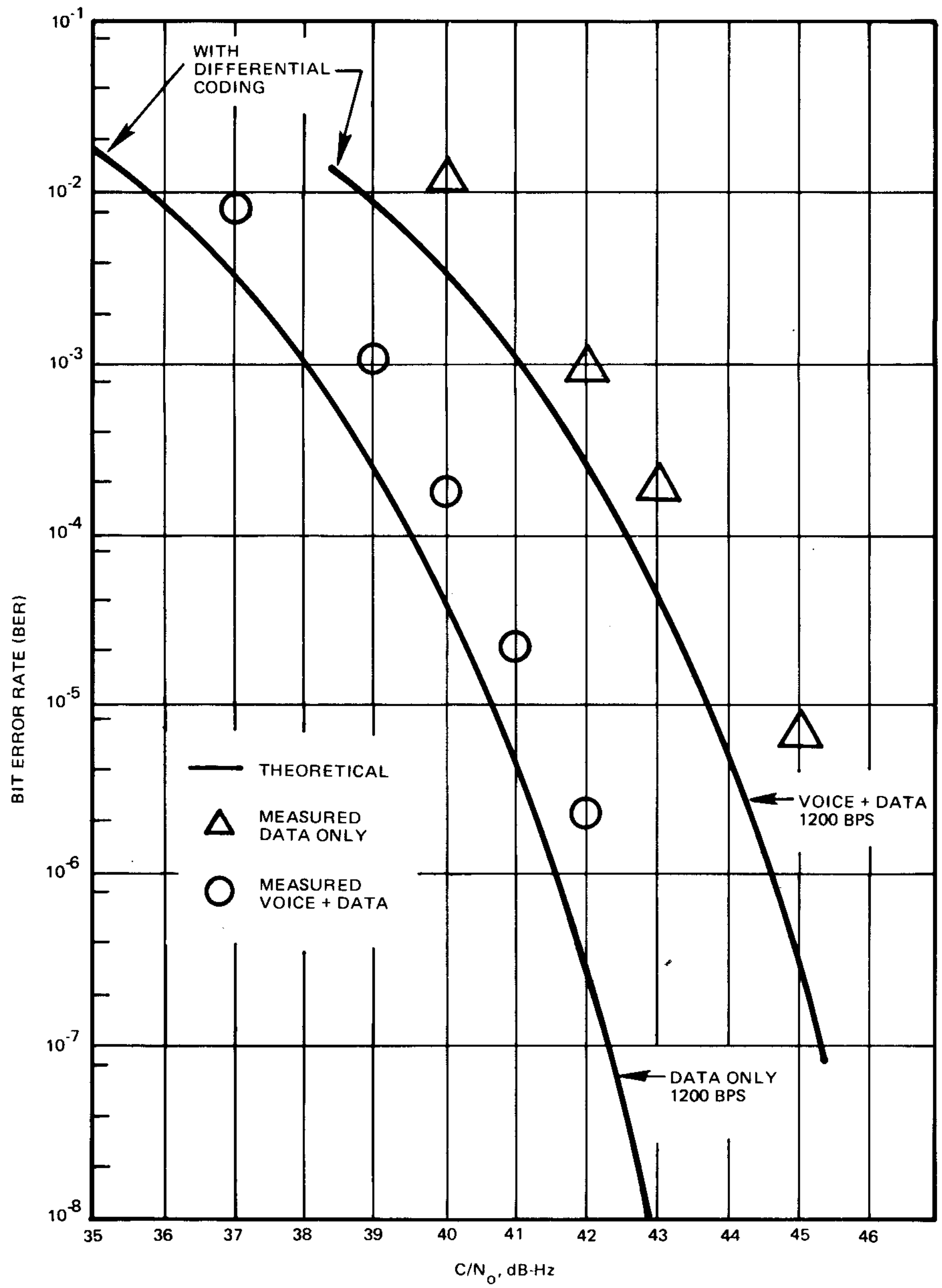

Fig 7 - Theoretical and Measured BER Performance or 1200 bps Data

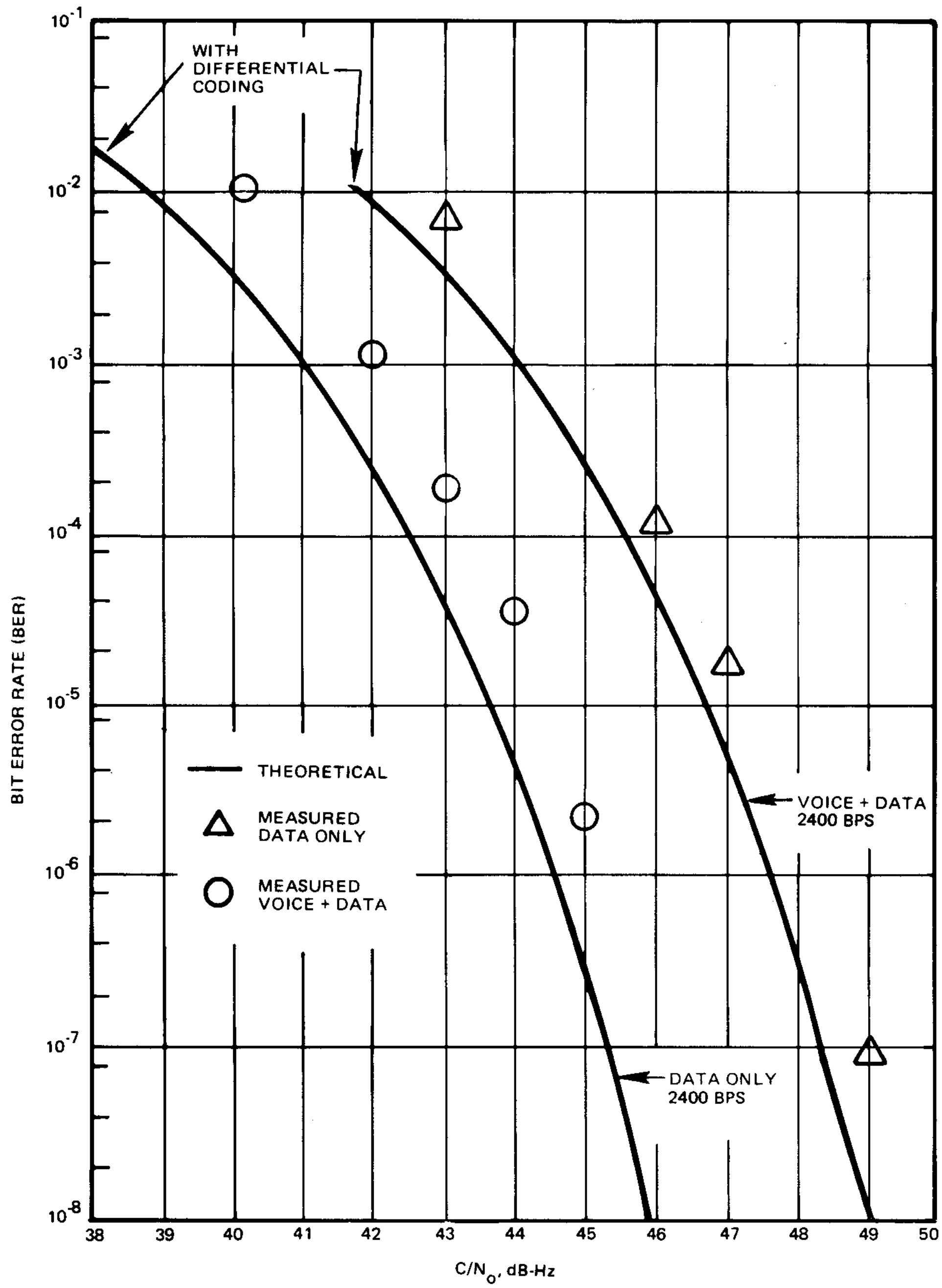

Fig 8 - Theoretical and Measured BER Performance for 2400 bps Data

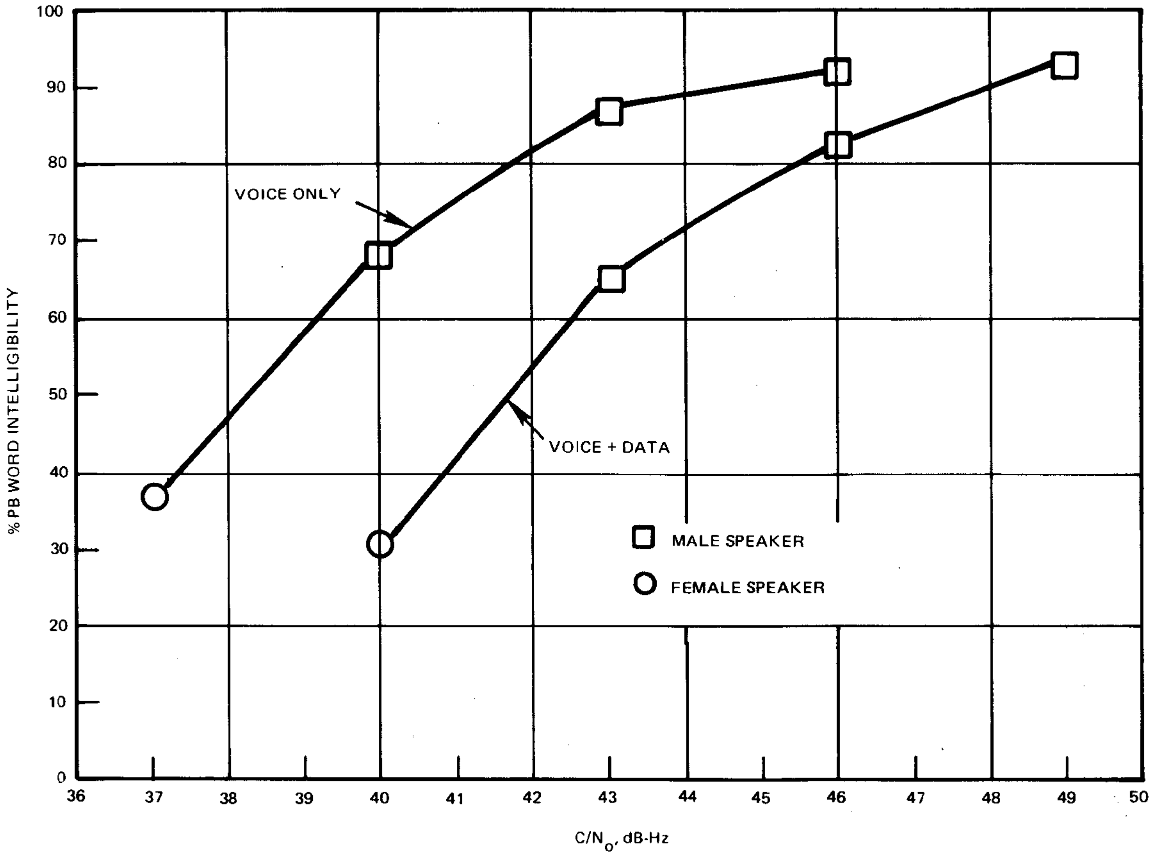

Fig. 9 - 50-Word PB Lists Voice Intelligibility Test Data

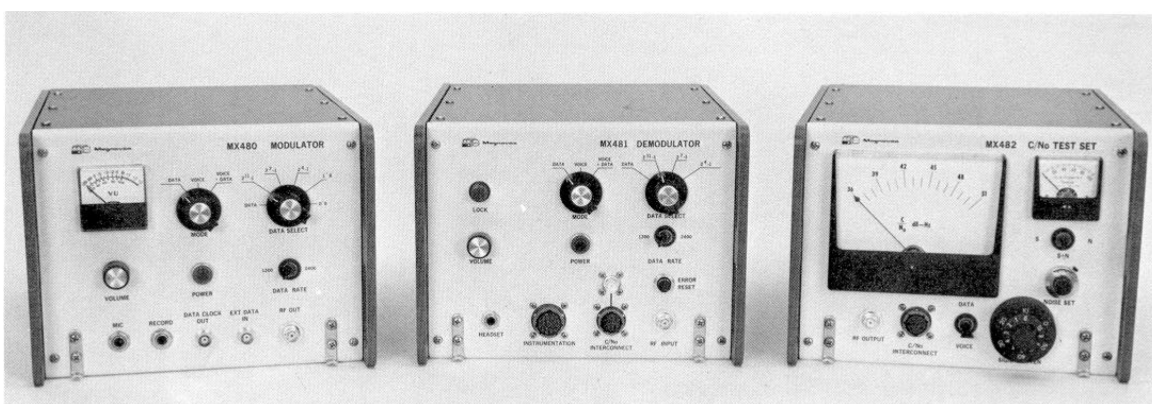

Fig. 10 - Sideband-Lock Modulator/Demodulator Units and C/N$_o$ Test Set