TECHNICAL REPORT NO. 3

Project A-852

SPECTRAL STUDIES OF SIGNALS PRESENT IN THE COMMAND AND COMMUNICATIONS SYSTEM UP-LINK TRANSMITTER

R. D. WETHERINGTON AND J. R. WALSH

Contract NAS8-20054

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Prepared for
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Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
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FOREWORD

This report was prepared at the Georgia Tech Engineering Experiment Station under contract NAS8-20054. It describes methods of calculating the frequency spectra of various portions of the Command and Communications System. The authors wish to express their appreciation to Mrs. Z. A. Huntoon, who did the major portion of the mathematical analysis and to Mr. W. B. Warren for his valuable assistance in the analysis of the problems encountered in this work.

Respectfully submitted:

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ABSTRACT

This report describes the results of an investigation to derive mathematical methods for calculating the frequency spectrum at several points of interest in the Command and Communications System, and of implementing these methods on a digital computer so that the various spectra could be obtained. Methods are presented for the calculation of the baseband spectrum of the biphase modulated command data signal, the baseband spectrum of the range code, the spectrum produced by the frequency modulated command data subcarrier generator, and the spectra of the phase modulated S-band carrier for various modulating signals. The S-band spectra were obtained for input signals to the phase modulator which consisted of (1) the frequency modulated output of the command data subcarrier generator when modulated with the baseband command data signal (2) the range code signal, and (3) the range code signal and the unmodulated command data subcarrier. Results of all of the spectral calculations were compared with measured values obtained in the laboratory and good agreement was obtained. Computer programs written in ALGOL for the Burroughs B 5500 computer are included, as well as printouts of sample calculations.

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I. INTRODUCTION

This report presents the results of a portion of the technical program on Contract NAS8-20054. The objective of the overall program is to investigate techniques for improving Saturn V RF tracking and ranging systems. The particular task covered by this report was that of calculating the frequency spectra for various portions of the Command and Communications System. The purpose of this report is to present the methods used to calculate these spectra, results of the calculations, and comparisons of the calculated values with measurements actually made on the system in the laboratory.

Methods are presented for calculation of the frequency spectra of (1) the baseband signal at the output of the command modulator for an alternating bit pattern and an arbitrary sub-bit pattern, (2) the baseband spectra of the range code, (3) the output of the frequency modulated command subcarrier generator, and (4) the output of the up-link signal generator at S-band.

The S-band spectra has been obtained for modulating signals into the phase modulator consisting of (1) the command data subcarrier with the baseband modulation applied (2) the range code, and (3) the range code and the unmodulated command data subcarrier.

The methods derived mathematically for the calculation of the various spectra have been programmed on a Burroughs B 5500 computer and the results of these computations are given. The computer programs used and sample calculations are presented in the appendices.

The results presented provide the details of the spectra at the outputs of the various systems in the Command and Communications System. These results can be used to determine the spectrum occupancy of the various signals.

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II. SYSTEM DESCRIPTION

The generation of the output signal of the CCS up-link transmitter is rather complex and involves a number of steps. The essential elements of the signal generating equipment are shown in the block diagram of Figure 1.

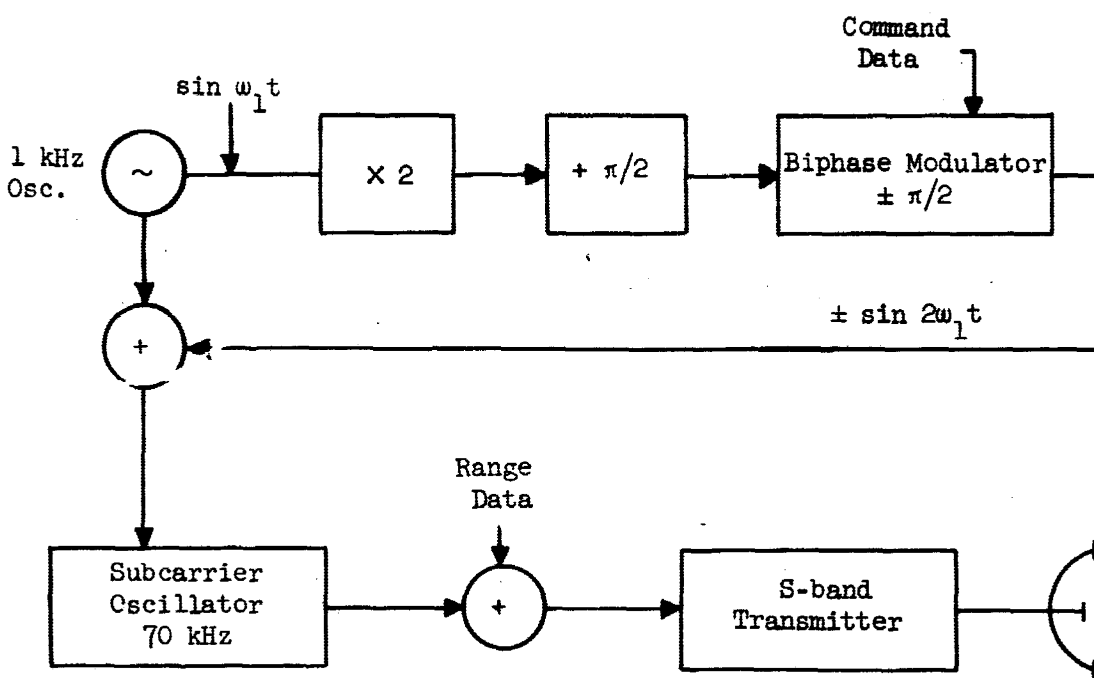


Figure 1. CCS up-link transmitter.

The output of a 1 kHz oscillator is passed through a frequency doubler to obtain a 2 kHz sine wave. This 2 kHz wave is then shifted $\frac{\pi}{2}$ radians in phase and passes through a biphase modulator which shifts the phase either $+\frac{\pi}{2}$ or $-\frac{\pi}{2}$ radians depending on a digital data stream arriving at 1000 bits per second. The output of the biphase modulator is then summed with the original 1 kHz wave of equal amplitude, the phases of the two waves being such that they pass through zero crossings at the same time. The output of the summing network is frequency modulated onto a 70 kHz subcarrier with the modulation level adjusted to give 5 kHz peak frequency deviation. The output of the FM subcarrier generator is phase modulated onto the S-band carrier. The modulation level is adjusted to give a maximum phase deviation of ± 1.22 radians.

The digital data stream which determines the phase shift introduced in the biphase modulator is actually composed of two parts. Command data is fed to the system at the rate of 200 bits per second, but each "bit" of data is injected into the biphase modulator as 5 "sub-bits". The particular 5 sub-bits chosen to represent a "one" data bit constitutes a code which is chosen prior to launch and is fixed for the flight. Once the sub-bit configuration is chosen to represent the "one" data bit, the complement of that set is the sub-bit code for the zero data bit. The sub-bit codes can be varied from one flight to the next. Thus the maximum "bit rate" at which command data is transmitted is 200 bits/sec, and the maximum sub-bit rate at which the biphase modulator switches is 1000 bits/sec.[1]

In addition to the command data entering the S-band phase modulator, there is present at times (but not always) a pseudo noise stream of rectangular pulses. These pulses, the range data code, are generated from a basic frequency of 498 kHz, so that the basic pulse interval is approximately 1 microsecond. The modulation level for this pulse string is adjusted to give a maximum phase deviation of the S-band carrier of ± 0.6 radians.

The operation of the command data channel is equivalently represented by the diagram shown in Figure 2, and this diagram will be used in the mathematical derivation. Figure 2 differs from Figure 1 only in that the phase shift of the 2 kHz wave of $\frac{\pi}{2}$ radians, followed by a biphase shift of $\pm\frac{\pi}{2}$ radians, is replaced by a biphase shift of $+\pi$ or 0 radians. The output is then equivalent to the original, but this form is somewhat more convenient mathematically.

Figure 3 shows the time waveform of the signals e_1, e_2, and e_3 shown in Figure 2 when the sub-bit pattern is alternating.

In addition to analyzing the spectrum out of the S-band transmitter, the spectra at other points have been developed. In particular, the spectrum of the signal out of the biphase modulator ($e_2(t)$ in Figure 2) and the spectrum out of the FM oscillator ($e_{FM}(t)$) have been calculated. Each of these spectra are discussed in the following sections in addition to treating the spectrum out of the S-band transmitter.

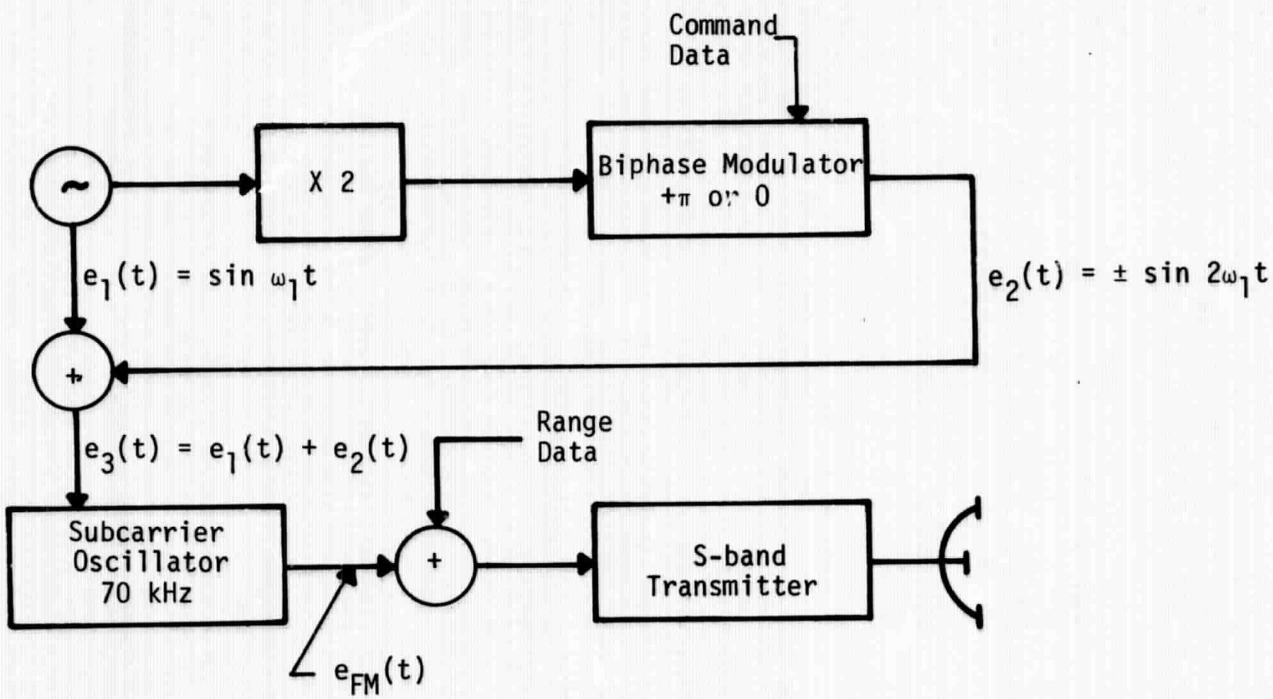


Figure 2. Equivalent representation of command data channel.

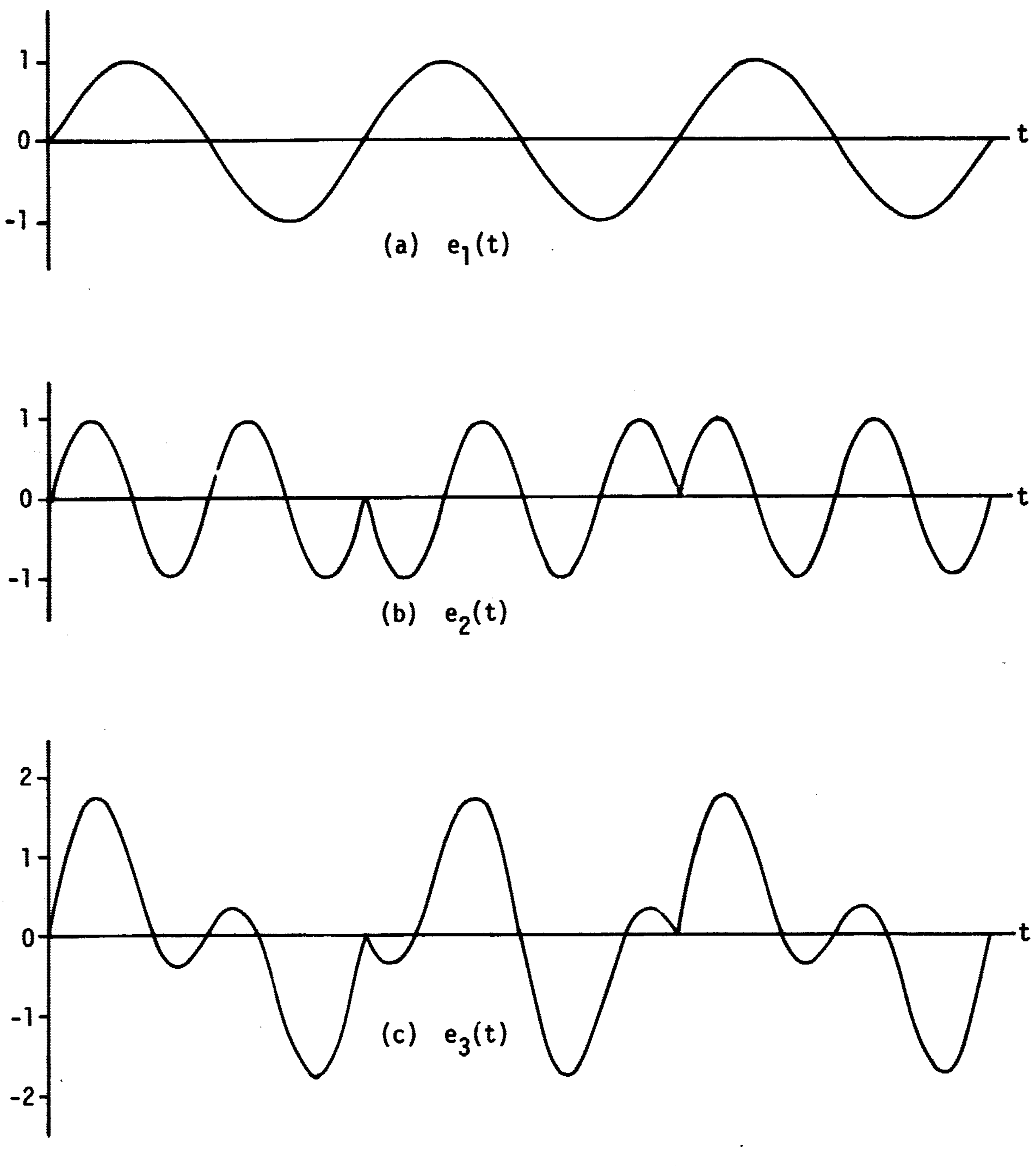


Figure 3. Time waveforms of baseband signals in the command data system.

III. SPECTRUM ANALYSIS

A. Spectra of Angle Modulated Signals

Since the circuits of the CCS transmitter use both frequency and phase modulation, some general considerations on deriving the spectra of such signals will be discussed first. Information can be modulated on a sinusoidal wave of the form

$$E(t) = A \cos (\omega_0 t + \varphi) \tag{1}$$

by varying either the amplitude factor A or the phase φ. If the latter is used then the wave is said to be angle modulated. Two particular forms of angle modulation are frequency modulation and phase modulation. These two differ only in the way in which φ is related to the modulating function. If we let $\psi(t)$ designate the modulating signal, and if

$$\varphi(t) = k_1 \psi(t) \quad , \tag{2}$$

Then the wave is phase modulated and the output signal is

$$E_{PM}(t) = A \cos [\omega_0 t + k_1 \psi(t)] \quad . \tag{3}$$

If, on the other hand

$$\varphi(t) = k_2 \int_0^t \psi(x)\, dx, \tag{4}$$

then the wave is frequency modulated and the output is

$$E_{FM}(t) = A \cos [\omega_0 t + k_2 \int_0^t \psi(x)\, dx] \quad . \tag{5}$$

Since Equations (3) and (5) differ only in the particular time function that represent φ, both types are adequately represented by Equation (1) provided φ is recognized as a function of time, i.e.,

$$E(t) = A \cos [\omega_o t + \varphi(t)] \quad . \tag{6}$$

Equation (6) may be written in exponential form as

$$E(t) = \frac{A}{2}[e^{j\omega_o t} e^{j\varphi(t)} + e^{-j\omega_o t} e^{-j\varphi(t)}] \quad . \tag{7}$$

The problem to be investigated is that of finding the spectral distribution of E(t), which is given by the Fourier transform of E(t), thus

$$E(\omega) = \mathcal{F} \left\{E(t)\right\} \quad . \tag{8}$$

In general the transform of the first term of Equation (7) will produce a set of spectral components centered about ω_o and the transform of the second term produces a set of components centered about $-\omega_o$. These two sets will be mirror images of each other; the total spectrum will be the sum of the two sets. Thus at each frequency, the contribution from the first set must be combined with the contribution from the second set to get the total spectral density at that frequency.

In many practical problems, however, the separation and spread of the two sets of components are such that there is no significant overlap between them. In such cases the positive and negative components can be computed separately. However, due to symmetry, it is sufficient to calculate only the positive components. This can be done by calculating

$$E'(\omega) = \mathcal{F} \left\{e^{j\omega_o t} e^{j\varphi(t)}\right\} \quad . \tag{9}$$

Since the Fourier transform of the product of two time functions is given by the convolution of the two transforms, Equation (9) may be rewritten as

$$E'(\omega) = \delta(\omega - \omega_o) * F(\omega) \tag{10}$$

where

$$F(\omega) = \mathcal{F}\left\{e^{j\varphi(t)}\right\} \quad . \tag{11}$$

The method outlined can be expanded in general to cover more than one modulating signal. If two modulating signals (such as two tones) are present and are represented by $\varphi_1(t)$ and $\varphi_2(t)$ then the (positive half) of the amplitude spectrum is given by

$$E'(\omega) = \mathcal{F}\left\{e^{j\omega_o t} \; e^{j\varphi_1(t)} \; e^{j\varphi_2(t)}\right\} \quad , \tag{12}$$

$$= \delta(\omega - \omega_o) * F_1(\omega) * F_2(\omega) \quad , \tag{13}$$

where

$$F_1(\omega) = \mathcal{F}\left\{e^{j\varphi_1(t)}\right\} \tag{14}$$

and

$$F_2(\omega) = \mathcal{F}\left\{e^{j\varphi_2(t)}\right\} \quad . \tag{15}$$

Or, in general, for the sum of n modulating signals $\varphi_1(t)$, $\varphi_2(t)$, ... $\varphi_n(t)$, the spectrum is

$$E'(\omega) = \delta(\omega - \omega_o) * F_1(\omega) * F_2(\omega) * --- * F_n(\omega) \quad , \qquad (16)$$

where

$$F_n(\omega) = \mathcal{F} \left\{ e^{j\varphi_n(t)} \right\} \quad , \qquad (17)$$

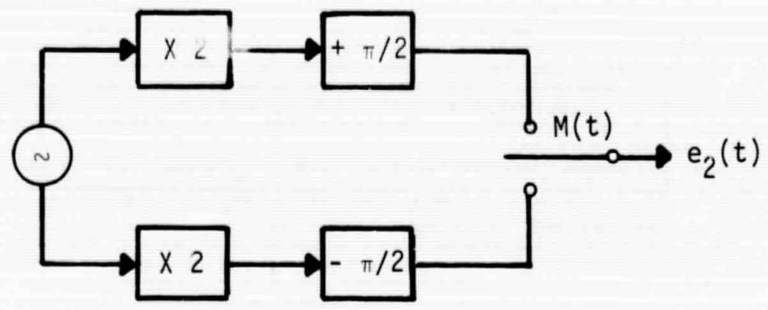
and each $\varphi_n(t)$ may be either a phase modulation (Equation (2)) or a frequency modulation (Equation (4)).

B. Application of General Method to CCS

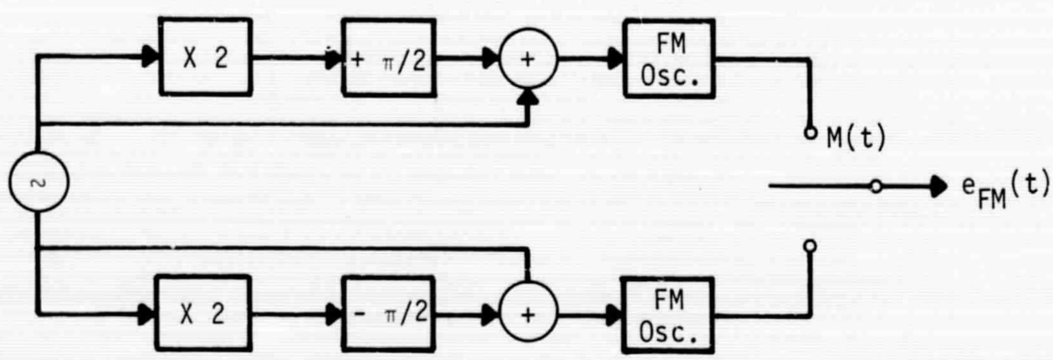
Although the above method will work in principle for any case of angle modulation, there may be practical difficulties in proceeding straight forward. The process of convolution is time-consuming and tedious to carry out. If the number of signal components in the modulating signal is large, as it often is, the direct approach may not be feasible. In such cases some manipulation of the signal components may be required to convert them into a form that permits use of the general convolution scheme.

For the CCS system, one manipulation that appeared desirable was that of finding some alternative method of mathematically treating the effect of the biphase modulator. The first approach in doing this was to view the system as a two channel system, one operating with a phase shift of $+\frac{\pi}{2}$ radians on the 2 kHz signal, and the other with a phase shift of $-\frac{\pi}{2}$ radians. The two channels were followed by a double throw switch which alternately selects channel 1 or channel 2 in agreement with the biphase switching rate. This switch would be located at the output of the system being considered, hence its location would depend on the point at which the spectrum was being calculated. Figure 4 shows diagrams of such a model for calculating the spectrum at (1) the output of the biphase modulator (2) the output of the FM subcarrier oscillator, and (3) at the output of the S-band transmitter. For each of these cases it was necessary to establish that the output signal of the model was mathematically equivalent to the corresponding signal in the CCS transmitter. It was possible to establish this point for the CCS system, although the proof depended on the periodic nature of the signals during each half of the switching cycle.

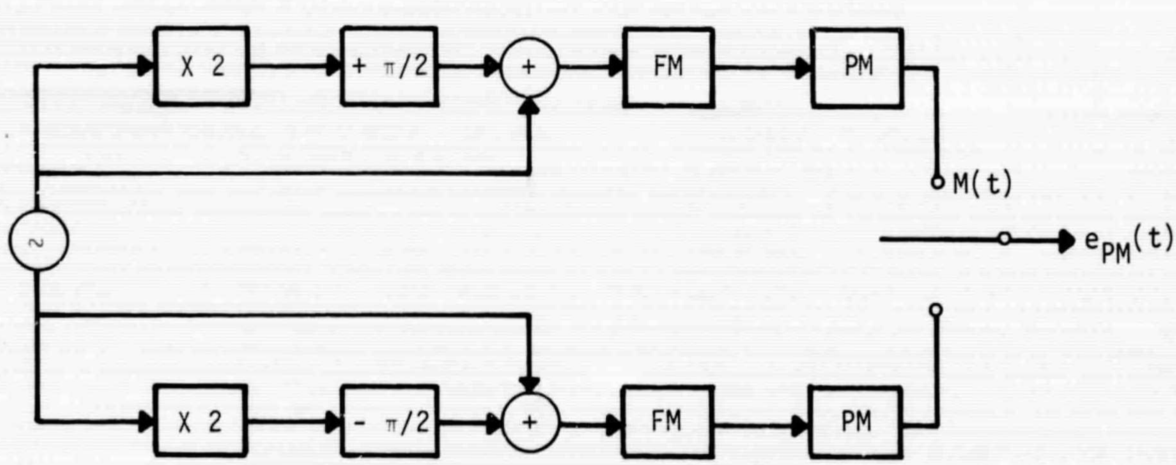
A somewhat simpler model, which is equivalent to the two channel



(a) Output of biphase modulator



(b) Output of FM subcarrier oscillator



(c) S-band output

Figure 4. Two-channel models for deriving the spectra of the command data baseband, FM, and PM signals.

model, is shown in Figure 5. Recognizing that the 2 kHz wave in one channel is simply the negative of the 2 kHz wave in the other channel, the model is collapsed into a single channel in which a multiplying function, M(t), which switches between + 1 and -1, is applied to the 2 kHz wave. This latter model was used in the spectral analyses discussed in the following sections.

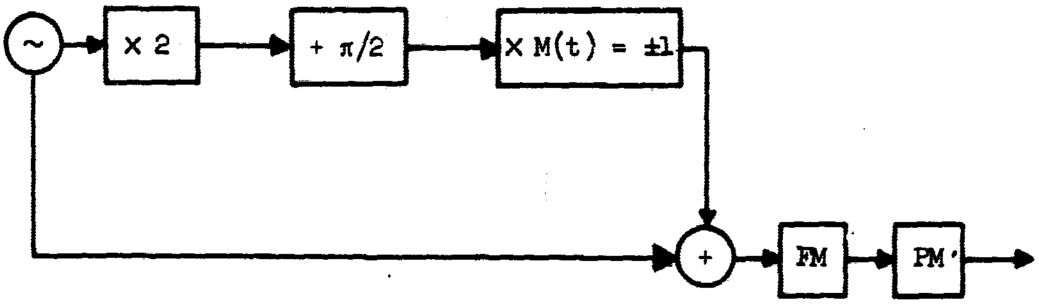


Figure 5. Single channel model with switching function M(t) replacing biphase modulator.

IV. BASEBAND SPECTRUM

The baseband spectrum is composed of two parts. One of these is the reference 1 kHz signal which is summed with equal amplitude to the output signal of the biphase modulator. The 1 kHz reference signal simply places a component in the baseband spectrum with an amplitude of E_o.

The output of the biphase modulator generates many spectral components. In the following analysis the spectrum of the biphase modulator output for an alternating sub-bit pattern is obtained.

For alternating sub-bits, the output of the biphase modulator is a sine wave which is switched 180° in phase at the sub-bit rate of 1000 bits per second. The time waveform can be depicted as the product of two functions (1) a sine wave of the proper frequency and amplitude, and (2) a square wave with an amplitude of one and a fundamental frequency of 500 Hz. Graphs of these two functions and the product function are shown in Figure 6. If ω_1 is the frequency of the original oscillator then the frequency of the sine wave out of the biphase modulator is $2\omega_1$. Also the fundamental frequency of the square-wave switching function is $\frac{\omega_1}{2}$. The output of the biphase modulator can be written as

$$e_2(t) = E_o \, M(t) \sin 2\omega_1 t \tag{18}$$

where M(t) is the switching function. Expanding M(t) into components using a Fourier Series gives

$$M(t) = \frac{4}{\pi}\left[\sin \frac{\omega_1}{2} t + \frac{1}{3} \sin \frac{3\omega_1}{2} t + \frac{1}{5} \sin \frac{5\omega_1}{2} t + \ldots\right] \; . \tag{19}$$

Substituting (19) into (18) gives

$$e_2(t) = \frac{4E_o}{\pi}\left[\sin 2\omega_1 t \sin \frac{\omega_1}{2} t + \frac{1}{3} \sin 2\omega_1 t \sin \frac{3\omega_1}{2} t + \frac{1}{5} \sin 2\omega_1 t \sin \frac{5\omega_1}{2} t + \ldots\right] \; . \tag{20}$$

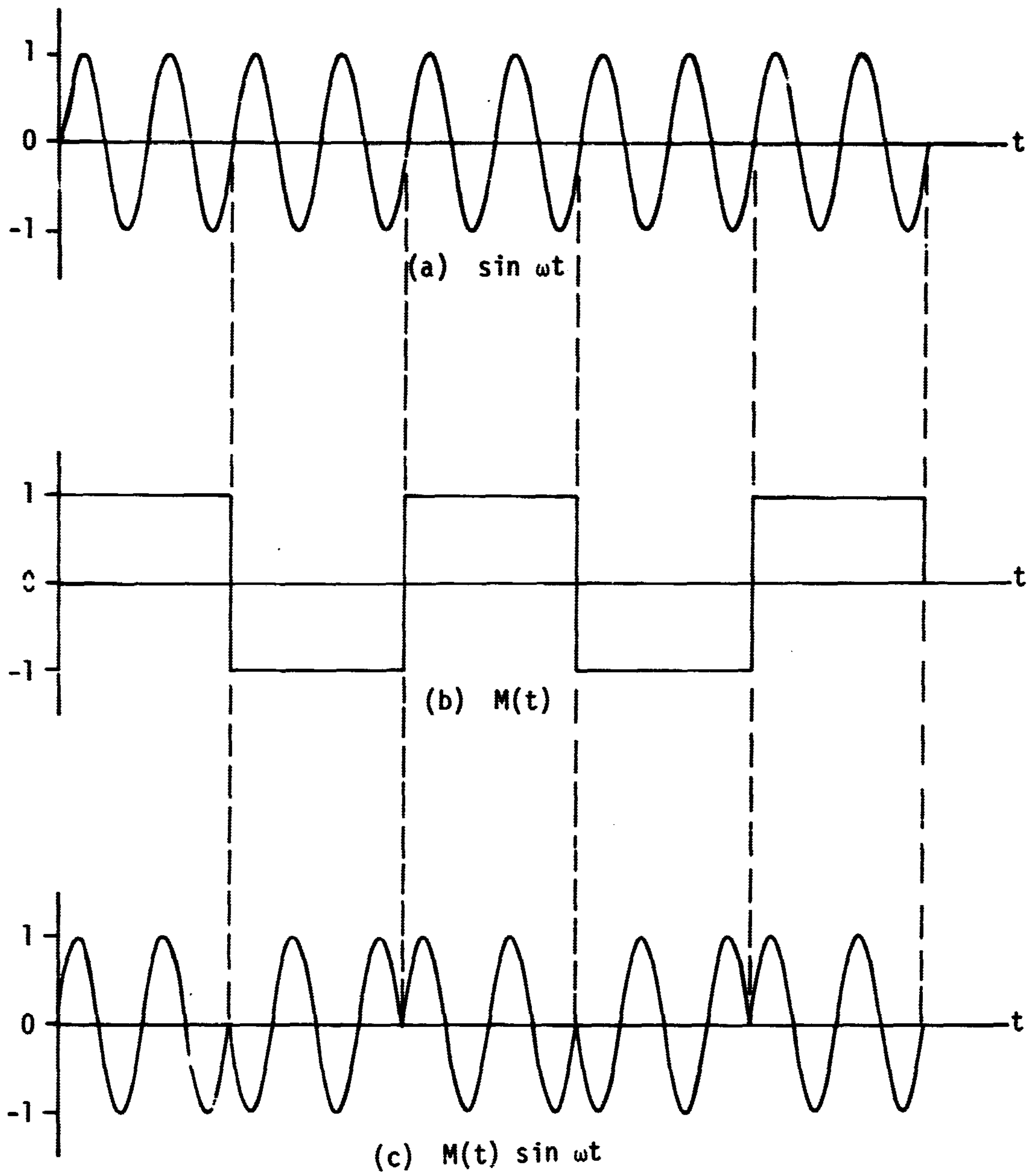


Figure 6. The two input components and resultant signal out of the biphase modulator.

Applying the identity

$$\sin A \sin B = \frac{1}{2}\left[\cos(A-B) - \cos(A+B)\right]$$

to each term gives

$$e_2(t) = \frac{2E_o}{\pi}\left[\cos\frac{3\omega_1}{2}t - \cos\frac{5\omega_1}{2}t\right.$$

$$+ \frac{1}{3}\cos\frac{\omega_1}{2}t - \frac{1}{3}\cos\frac{7\omega_1}{2}t$$

$$+ \frac{1}{5}\cos\frac{\omega_1}{2}t - \frac{1}{5}\cos\frac{9\omega_1}{2}t$$

$$+ \frac{1}{7}\cos\frac{3\omega_1}{2}t - \frac{1}{7}\cos\frac{11\omega_1}{2}t$$

$$+ \ldots \frac{1}{n}\cos\left(\frac{n-4}{2}\right)\omega_1 t - \frac{1}{n}\cos\left(\frac{n+4}{2}\right)\omega_1 t$$

$$\left. + \ldots\right], \quad n = 1, 3, 5, 7 \ldots \quad . \qquad (21)$$

For the CCS system, ω_1 corresponds to a frequency of 1.0 kHz, hence $\omega_1 = 2{,}000\pi$. Inserting this value gives

$$e_2(t) = \frac{2E_o}{\pi}\left[\cos 3000\pi t - \cos 5000\pi t\right.$$

$$+ \frac{1}{3}\cos 1000\pi t - \frac{1}{3}\cos 7000\pi t$$

$$+ \frac{1}{5}\cos 1000\pi t - \frac{1}{5}\cos 9000\pi t$$

$$\left. + \ldots\right] \quad . \qquad (22)$$

Collecting terms of the same frequency gives

$$e_2(t) = \frac{2E_o}{\pi}\left[\frac{8}{15}\cos 1000\pi t + \frac{8}{7}\cos 3000\pi t\right.$$

$$- \frac{8}{9}\cos 5000\pi t - \frac{8}{33}\cos 7000\pi t$$

$$- \frac{8}{65}\cos 9000\pi t - \ldots$$

$$\left. - \frac{8}{(2n-5)(2n+3)}\cos (2n-1)\, 1000\pi t \ldots\right] . \qquad (23)$$

A graph of the amplitude spectrum $E_2(\omega)$ corresponding to $e_2(t)$ is shown as the solid lines in Figure 7.

To obtain the complete baseband spectrum the 1 kHz reference signal component must be added to the output spectrum of the biphase modulator derived in the preceeding paragraphs. This component is shown in Figure 7 as the broken line.

This spectrum represents the spectrum that would be expected with ideal (distortionless) signals. In practice it must be remembered that a signal with harmonic distortion of less than 0.1 per cent is rare.

As a check on the calculated values, a laboratory version of the biphase modulator was constructed and the components of the output spectrum corresponding to the calculated components were measured. The measured values are indicated in Figure 7 by the dots. The small differences could easily be due to distortion in the laboratory model of the modulator.

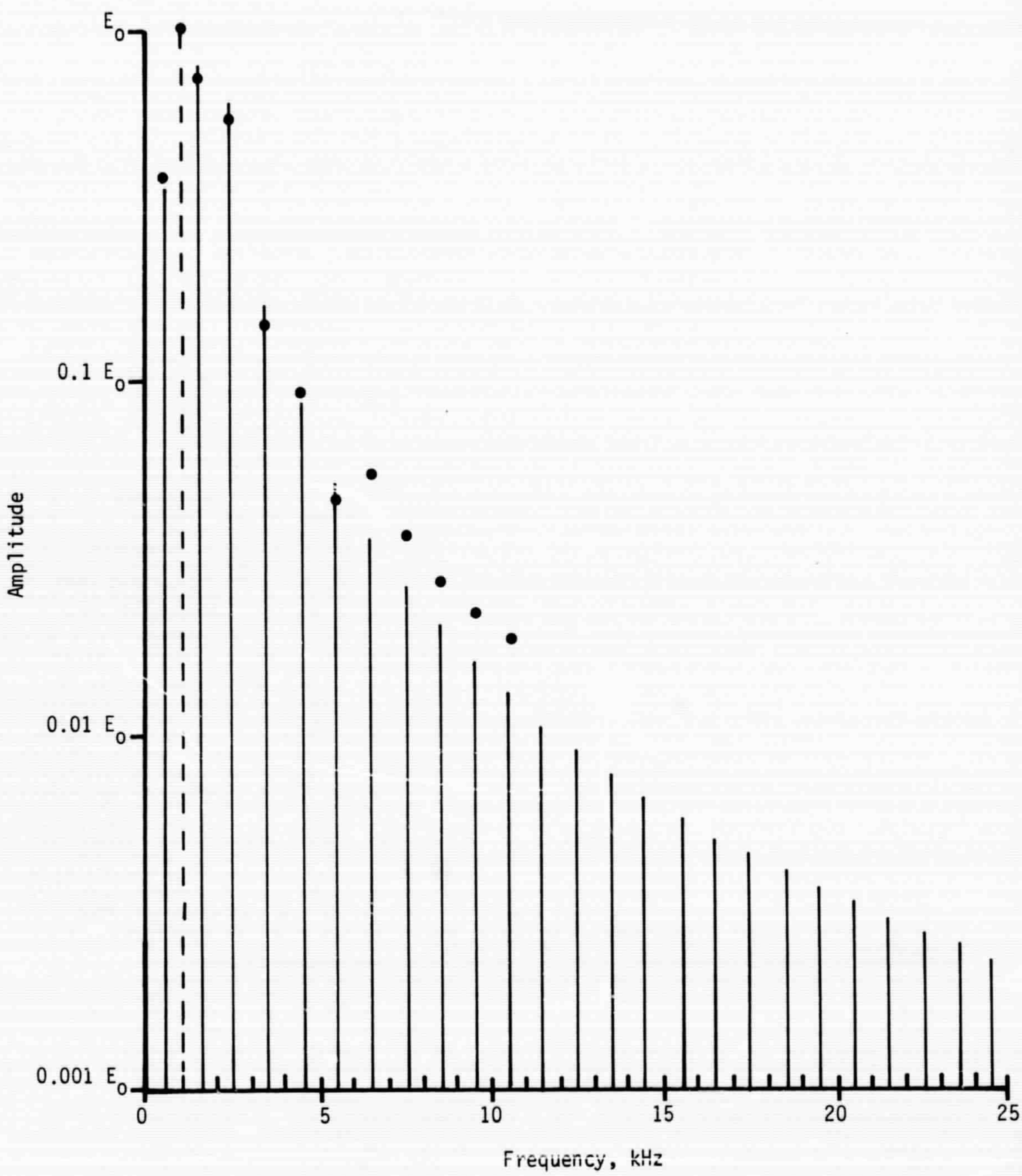


Figure 7. Computed baseband spectra of the command modulator. Comparative measured values are indicated by dots.

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V. FM SPECTRUM

A. Derivation of Equations

For a derivation of the FM spectrum, a function X(t) was defined to represent the effect of the sub-bit code. A diagram of the system is shown in Figure 8.

The original oscillator signal, represented as $\sin \omega_1 t$, is passed through a doubler to obtain $\sin 2\omega_1 t$. This signal is then operated on by a coder which impresses the sub-bit code by switching the phase by π or 0 radians. The output of the coder, either $\sin 2\omega_1 t$ or $- \sin 2\omega_1 t$ depending on the phase shift introduced by the coder, can be represented by

$$e'(t) = X(t) \sin 2\omega_1 t \tag{24}$$

where
$$X(t) = \sum_{\mu=1}^{5} X_\mu(t) \tag{25}$$

and
$$X_\mu = I_\mu \tag{26}$$

with I taking on only values of either + 1 or -1 (the particular value, +1 or -1 for each value of μ can be arbitrarily selected). The sequence of I_μ's represents the sub-bit code.

If the coding is fixed, X(t) can be thought of as a sum of periodic pulse trains, each with period $10\pi/\omega_1$, or 5 milliseconds.

Following coding, the signal is passed through a biphase modulator which switches the phase by π or 0 radians depending on the digital data stream. This action is represented by multiplying by the function M(t), which only takes on values of +1 or -1 depending on the digital data stream. The output of the biphase modulator is thus

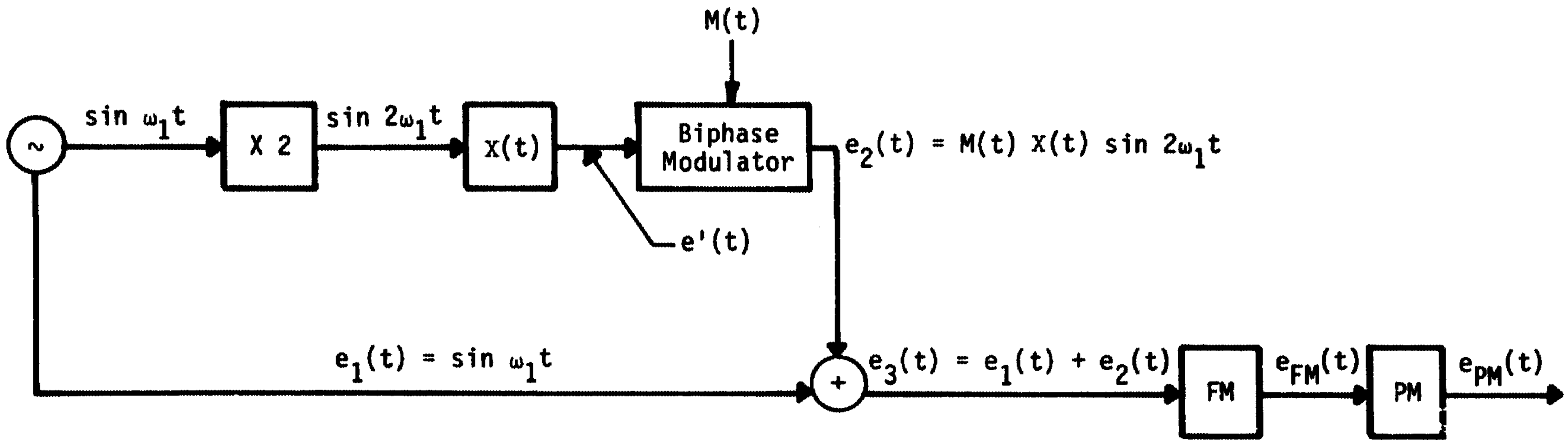


Figure 8. Model of the command data channel.

$$e_2(t) = M(t)X(t)\sin 2\omega_1 t \quad . \tag{27}$$

This signal is then added to the original oscillator output

$$e_1(t) = \sin \omega_1 t \tag{28}$$

to obtain the complete signal going into the FM modulator, which is

$$e_3(t) = \sin \omega_1 t + M(t)X(t)\sin 2\omega_1 t \quad . \tag{29}$$

If the FM oscillator carrier frequency is ω_c, the signal out of the oscillator is

$$e_{FM}(t) = \cos\left[\omega_c t + k\int_0^t e_3(x)\, dx\right] \quad . \tag{30}$$

To evaluate the integral appearing in Equation (30) it may be written as

$$k\int_0^t e_3(x)\, dx = k\int_0^t e_1(x)\, dx + k\int_0^t e_2(x)\, dx \quad . \tag{31}$$

The first integral in Equation (31) presents no difficulty

$$\begin{aligned} k\int_0^t e_1(x)\, dx &= k\int_0^t \sin \omega_1 x\, dx \\ &= k\left[\frac{-\cos \omega_1 x}{\omega_1}\right]_0^t \\ &= \frac{k}{\omega_1}\left[1 - \cos \omega_1 t\right] \quad . \end{aligned} \tag{32}$$

For the second integral

$$k\int_0^t e_2(x)\ dx = k\int_0^t M(x)X(x)\ \sin 2\omega_1 x\ dx \quad . \tag{33}$$

The range of integration can be thought of as a succession of integrals of length $2\pi/\omega_1$, plus a final integral of arbitrary length. That is,

Equation (33) can be written as

$$k\int_0^t e_2(x)\ dx = k\int_0^{\frac{2\pi}{\omega_1}} e_2(x)\ dx + k\int_{\frac{2\pi}{\omega_1}}^{\frac{4\pi}{\omega_1}} e_2(x)\ dx + \ldots$$

$$\ldots + k\int_{\frac{2(n-1)\pi}{\omega_1}}^{\frac{2n\pi}{\omega_1}} e_2(x)\ dx + k\int_{\frac{2n\pi}{\omega_1}}^{t} e_2(x)\ dx \quad . \tag{34}$$

Within any interval $\frac{2(p-1)\pi}{\omega_1} < x < \frac{2p\pi}{\omega_1}$, $M(t)X(t)$ is constant (either + 1 or -1) and can be removed, thus

$$k\int_{\frac{2(p-1)\pi}{\omega_1}}^{\frac{2p\pi}{\omega_1}} M(x)X(x)\ \sin 2\omega_1 x\ dx = \pm\, k\int_{\frac{2(p-1)\pi}{\omega_1}}^{\frac{2p\pi}{\omega_1}} \sin 2\omega_1 x\ dx$$

$$= \pm\, k\left[-\frac{\cos 2\omega_1 x}{2\omega_1}\right]_{\frac{2(p-1)\pi}{\omega_1}}^{\frac{2p\pi}{\omega_1}}$$

$$= \pm\,\frac{k}{2\omega_1}\left[-\cos 4p\pi + \cos(4p-4)\pi\right] = 0\ . \tag{35}$$

It follows that only the last integral in Equation (34) is non-zero and that $M(x)X(x) = M(t)X(t)$ throughout the interval of integration, thus

$$k\int_0^t e_2(x)\,dx = k\int_{\frac{2n\pi}{\omega_1}}^{t} M(t)X(t)\sin 2\omega_1 x\,dx$$

$$= k\int_{\frac{2n\pi}{\omega_1}}^{t} \sin 2\omega_1 x\,dx \quad \text{if } M(t)X(t) = 1 \quad , \tag{36}$$

and

$$= -k\int_{\frac{2n\pi}{\omega_1}}^{t} \sin 2\omega_1 x\,dx \quad \text{if } M(t)X(t) = -1 \quad . \tag{37}$$

Since both results are correctly indicated if $M(t)X(t)$ is removed from under the integral sign, then

$$k\int_0^t e_2(x)\,dx = kM(t)X(t)\int_{\frac{2n\pi}{\omega_1}}^{t} \sin 2\omega_1 x\,dx$$

$$= kM(t)X(t)\left[-\frac{\cos 2\omega_1 x}{2\omega_1}\right]_{\frac{2n\pi}{\omega_1}}^{t}$$

$$= \frac{kM(t)X(t)}{2\omega_1}\left[-\cos 2\omega_1 t + \cos 4n\pi\right]$$

$$= \frac{kM(t)X(t)}{2\omega_1}\left[1 - \cos 2\omega_1 t\right] \quad . \tag{38}$$

Inserting the results of Equations (32) and (38) into Equation (30) gives

$$e_{FM}(t) = \cos\left\{\omega_c t + \frac{k}{\omega_1}[1 - \cos \omega_1 t] + \frac{k}{2\omega_1} M(t)X(t)[1 - \cos 2\omega_1 t]\right\} \quad . \quad (39)$$

Let

$$\lambda = \frac{k}{\omega_1} \quad , \quad (40)$$

$$\varphi_1(t) = 1 - \cos \omega_1 t, \text{ and} \quad (41)$$

$$\varphi_2(t) = 1 - \cos 2\omega_1 t \quad . \quad (42)$$

Then Equation (39) can be rewritten as

$$\begin{aligned} e_{FM}(t) &= \cos\left\{\omega_c t + \lambda\varphi_1(t) + \frac{\lambda}{2} M(t)X(t)\varphi_2(t)\right\} \\ &= \cos[\omega_c t + \lambda\varphi_1(t)] \cos[\frac{\lambda}{2} M(t)X(t)\varphi_2(t)] \\ &\quad - \sin[\omega_c t + \lambda\varphi_1(t)] \sin[\frac{\lambda}{2} M(t)X(t)\varphi_2(t)] \quad . \quad (43) \end{aligned}$$

Note that

$$\cos[\frac{\lambda}{2} M(t)X(t)\varphi_2(t)] = \cos[\frac{\lambda}{2}\varphi_2(t)], \quad M(t)X(t) = \pm 1, \quad (44)$$

and

$$\begin{aligned} \sin[\frac{\lambda}{2} M(t)X(t)\varphi_2(t)] &= \sin[\frac{\lambda}{2}\varphi_2(t)], \quad M(t)X(t) = +1 \\ &= -\sin[\frac{\lambda}{2}\varphi_2(t)], \quad M(t)X(t) = -1 \quad . \quad (45) \end{aligned}$$

Therefore the sine function can be written as

$$\sin\left[\frac{\lambda}{2} M(t)X(t)\varphi_2(t)\right] = M(t)X(t)\sin\left[\frac{\lambda}{2}\varphi_2(t)\right] \tag{46}$$

for all M(t)X(t); thus Equation (43) becomes

$$e_{FM}(t) = \cos\left[\omega_c t + \lambda\varphi_1(t)\right]\cos\left[\frac{\lambda}{2}\varphi_2(t)\right]$$

$$-M(t)X(t)\sin\left[\omega_c t + \lambda\varphi_1(t)\right]\sin\left[\frac{\lambda}{2}\varphi_2(t)\right], \quad \text{or} \tag{47}$$

$$e_{FM}(t) = \frac{1}{2} e^{j\omega_c t} e^{j\lambda\varphi_1(t)}\left\{\cos\left[\frac{\lambda}{2}\varphi_2(t)\right] - \frac{M(t)X(t)}{j}\sin\left[\frac{\lambda}{2}\varphi_2(t)\right]\right\}$$

$$+ \frac{1}{2} e^{-j\omega_c t} e^{-j\lambda\varphi_1(t)}\left\{\cos\left[\frac{\lambda}{2}\varphi_2(t)\right] + \frac{M(t)X(t)}{j}\sin\left[\frac{\lambda}{2}\varphi_2(t)\right]\right\} . \tag{48}$$

Assuming that the spread of spectral lines about ω_c and $-\omega_c$ is small so that there is no significant overlap between the two sets (and the two are symmetrical), the problem can be reduced to considering only those components in the neighborhood of ω_c, i.e., consider only the first term of Equation (48). This reduces the problem to

$$e_{FM}(t) = e^{j\omega_c t} e^{j\lambda\varphi_1(t)}\left\{\cos\left[\frac{\lambda}{2}\varphi_2(t)\right] + jM(t)X(t)\sin\left[\frac{\lambda}{2}\varphi_2(t)\right]\right\}$$

$$= e^{j\omega_c t} S_1(t)\left[S_2(t) + jM(t)X(t)S_3(t)\right] . \tag{49}$$

Define

$$S_1(\omega) = \mathfrak{F}\left[e^{j\lambda\varphi_1(t)}\right] \quad , \tag{50}$$

$$S_2(\omega) = \mathfrak{F}\left[\cos\left(\frac{\lambda}{2}\,\varphi_2(t)\right)\right] \quad , \tag{51}$$

$$S_3(\omega) = \mathfrak{F}\left[\sin\left(\frac{\lambda}{2}\,\varphi_2(t)\right)\right] \quad , \tag{52}$$

$$M(\omega) = \mathfrak{F}\,[M(t)] \quad , \text{ and} \tag{53}$$

$$X(\omega) = \mathfrak{F}\,[X(t)] \quad . \tag{54}$$

Then the spectrum can be written as

$$\begin{aligned} E_{FM}(\omega) &= \mathfrak{F}\,[e_{FM}(t)] \\ &= \delta(\omega - \omega_c) * S_1(\omega) * \left\{S_2(\omega) + jM(\omega) * X(\omega) * S_3(\omega)\right\} \quad . \end{aligned} \tag{55}$$

To evaluate the individual components of the spectrum, consider first the time function, $S_1(t)$, whose transform yields $S_1(\omega)$.

$$\begin{aligned} S_1(t) &= e^{j\lambda(1 - \cos\omega_1 t)} \\ &= e^{j\lambda}\, e^{-j\lambda\cos\omega_1 t} \\ &= e^{j\lambda}\, e^{j\lambda\sin(\omega_1 t - \frac{\pi}{2})} \quad . \end{aligned} \tag{56}$$

which, by the use of Sommerfield's Integral [2], can be expanded in a Fourier series to give

$$S_1(t) = \sum_{n=-\infty}^{\infty} e^{j\lambda}\, J_n(\lambda)\, e^{-jn\frac{\pi}{2}}\, e^{jn\omega_1 t} \quad , \tag{57}$$

hence

$$S_1(\omega) = \sum_{n=-\infty}^{\infty} e^{j\lambda} J_n(\lambda)\, e^{-jn\frac{\pi}{2}}\, \delta(\omega - n\omega_1) \tag{58}$$

$$= \sum_{n=-\infty}^{\infty} J(\lambda)[\cos(\lambda - n\tfrac{\pi}{2}) + j \sin(\lambda - n\tfrac{\pi}{2})]\, \delta(\omega - n\omega_1) \quad . \tag{59}$$

Similarly, let

$$S_2(t) = \cos\left[\frac{\lambda}{2}\varphi_2(t)\right]$$

$$= \frac{1}{2}\left[e^{j\frac{\lambda}{2}\varphi_2(t)} + e^{-j\frac{\lambda}{2}\varphi_2(t)}\right]$$

$$= \frac{1}{2}\left[e^{j\frac{\lambda}{2}(1 - \cos 2\omega_1 t)} + e^{-j\frac{\lambda}{2}(1 - \cos 2\omega_1 t)}\right]$$

$$= \frac{1}{2}\left[e^{j\frac{\lambda}{2}}\, e^{j\frac{\lambda}{2}\sin(2\omega_1 t - \frac{\pi}{2})} + e^{-j\frac{\lambda}{2}}\, e^{j\frac{\lambda}{2}\sin(2\omega_1 t + \frac{\pi}{2})}\right], \text{ or} \tag{60}$$

$$S_2(t) = \frac{1}{2}\left[\sum_{n=-\infty}^{\infty} e^{j\frac{\lambda}{2}} J_n(\tfrac{\lambda}{2})\, e^{j2n\omega_1 t}\, e^{-jn\frac{\pi}{2}} + \sum_{n=-\infty}^{\infty} e^{-j\frac{\lambda}{2}} J_n(\tfrac{\lambda}{2})\, e^{j2n\omega_1 t}\, e^{jn\frac{\pi}{2}}\right]$$

$$= \frac{1}{2}\sum_{n=-\infty}^{\infty} J_n(\tfrac{\lambda}{2})\left[e^{j(\frac{\lambda}{2} - n\frac{\pi}{2})} + e^{-j(\frac{\lambda}{2} - n\frac{\pi}{2})}\right] e^{j2n\omega_1 t}$$

$$= \sum_{n=-\infty}^{\infty} J_n(\tfrac{\lambda}{2}) \cos(\tfrac{\lambda}{2} - n\tfrac{\pi}{2})\, e^{j2n\omega_1 t} \quad , \tag{61}$$

hence

$$S_2(\omega) = \sum_{n=-\infty}^{\infty} J_n(\tfrac{\lambda}{2}) \cos(\tfrac{\lambda}{2} - \tfrac{n\pi}{2})\, \delta(\omega - 2n\omega_1) \quad . \qquad (62)$$

Applying a similar treatment to

$$S_3(t) = \sin(\tfrac{\lambda}{2}\, \varphi_2(t)) \qquad (63)$$

gives

$$S_3(\omega) = \sum_{n=-\infty}^{\infty} J_n(\tfrac{\lambda}{2}) \sin(\tfrac{\lambda}{2} - \tfrac{n\pi}{2})\, \delta(\omega - 2n\omega_1) \quad . \qquad (64)$$

To find the spectrum of the bit switching function M(t) for an alternating sequence of 1's and 0's, note that M is the periodic square wave shown in Figure 9.

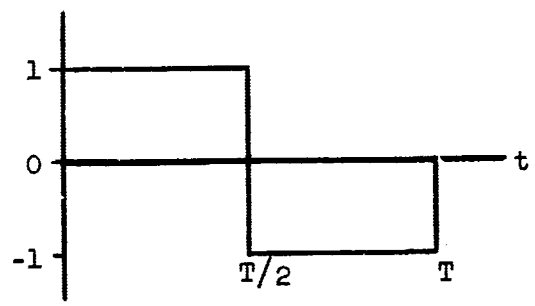


Figure 9. Time waveform of M(t) for alternating bits.

Expanding in a Fourier series gives

$$M(t) = \sum_{n=-\infty}^{\infty} C_n \, e^{j\frac{2\pi nt}{T}} \quad , \qquad (65)$$

where

$$C_o = \frac{1}{T}\left[\int_0^{T/2} (1)\, dt + \int_{T/2}^{T} (-1)\, dt\right] = 0 \quad , \tag{66}$$

and

$$C_n = \frac{1}{T}\left[\int_0^{T/2} e^{-j(\frac{2\pi n}{T})t}\, dt - \int_{T/2}^{T} e^{-j(\frac{2\pi n}{T})t}\, dt\right]$$

$$= -\frac{1}{j2\pi n}\left[e^{-j\pi n} - 1 - e^{-j2\pi n} + e^{-j\pi n}\right] \quad , \tag{67}$$

which reduces to

$$C_n = \frac{j}{\pi}\left[\frac{(-1)^n - 1}{n}\right] \quad . \tag{68}$$

Hence

$$M(t) = \sum_{n=-\infty}^{\infty} \frac{j[(-1)^n - 1]}{\pi n}\, e^{\frac{j(2\pi n)t}{T}} \quad . \tag{69}$$

Denoting the fundamental frequency by

$$\omega_2 = \frac{2\pi}{T} \quad , \tag{70}$$

then

$$M(\omega) = \sum_{n=-\infty}^{\infty} \frac{j[(-1)^n - 1]}{\pi n}\, \delta(\omega - n\omega_2) \quad , \tag{71}$$

and ~ince one cycle of M(t) spans 10 cycles of the 1 kHz frequency, it follows that

$$\omega_2 = \frac{\omega_1}{10} \quad . \tag{72}$$

The function X(t), which represents the sub-bit pattern, is periodic with a period of five milliseconds. The period is divided into five sub-intervals of one millisecond each. Within each sub-interval the function has a constant value of either +1 or -1, depending on the particular sub-bit associated with that interval. To find the spectrum let

$$X(t) = \sum_{\mu=1}^{5} X_\mu(t) \quad , \tag{73}$$

where

$$X_\mu(t) = I_\mu, \qquad nT + t_{\mu-1} \le t \le nT + t_\mu \quad , \tag{74}$$

and

$$T = \frac{10\pi}{\omega_1} \quad .$$

First, the spectrum for a single sub-bit will be obtained. Consider the sub-bit represented by $X_\mu(t)$ as shown in Figure 10.

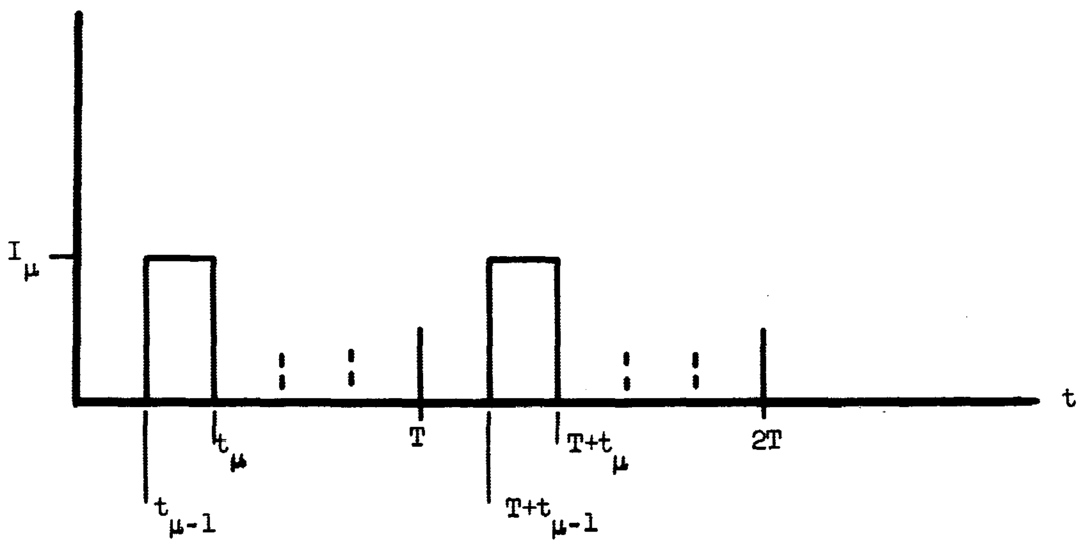


Figure 10. Time waveform for a single sub-bit $X_\mu(t)$.

Expanding $X_\mu(t)$ in a Fourier Series gives

$$X_\mu(t) = \sum_{n=-\infty}^{\infty} C_{\mu,n} e^{jn\omega_3 t} \quad , \text{ where} \tag{75}$$

$$\omega_3 = \frac{2\pi}{T} = \frac{\omega_1}{5}$$

$$C_{\mu,n} = \frac{1}{T}\int_0^T X_\mu(t) e^{-jn\omega_3 t}\, dt \tag{76}$$

$$= \frac{1}{T}\int_{t_{\mu-1}}^{t_\mu} I_\mu \, e^{-jn\omega_3 t}\, dt \tag{77}$$

$$= \frac{I_\mu}{-jn\omega_3 T}\left[e^{-jn\omega_3 t_\mu} - e^{-jn\omega_3 t_{\mu-1}}\right] \tag{78}$$

$$= \frac{I_\mu}{-jn\omega_3\left(\frac{2\pi}{\omega_3}\right)}\left[e^{-jn\omega_3\left(\frac{2\pi\mu}{\omega_1}\right)} - e^{-jn\omega_3 \frac{2\pi(\mu-1)}{\omega_1}}\right] \tag{79}$$

$$= \frac{jI_\mu}{2\pi n}\left[e^{-j\left(\frac{2\pi n}{5}\right)\mu} - e^{-j\left(\frac{2\pi n}{5}\right)(\mu-1)}\right] \quad . \tag{80}$$

Therefore the spectrum of a single sub-bit is

$$X_\mu(\omega) = \sum_n \frac{jI_\mu}{2\pi n}\left[e^{-j\left(\frac{2\pi n}{5}\right)\mu} - e^{-j\left(\frac{2\pi n}{5}\right)(\mu-1)}\right]\delta(\omega - n\omega_3) \quad , \tag{81}$$

and the spectrum for all five sub-bits is obtained simply by summing over the five values of μ, hence

$$X(\omega) = j\sum_n \sum_\mu \frac{I_\mu}{2\pi n}\left[e^{-j\left(\frac{2\pi n}{5}\right)\mu} - e^{-j\left(\frac{2\pi n}{5}\right)(\mu-1)}\right]\delta(\omega - n\omega_3) \quad . \tag{82}$$

Replacing the exponentials in (82) with sine and cosine functions, $X(\omega)$ can be expressed in various ways by application of trignometric identities. The form selected as most convenient for making calculations is

$$X(\omega) = \sum_{n=-\infty}^{\infty} \left\{ \sum_{\mu=1}^{5} [I_\mu \cos(2\mu-1)\frac{n\pi}{5} - jI_\mu \sin(2\mu-1)\frac{n\pi}{5}] \right\} \frac{\sin \frac{n\pi}{5}}{\pi n} \delta(\omega - n\omega_3) \text{ , } \quad (83)$$

where

$$\omega_3 = \frac{\omega_1}{5} \quad ,$$

and $I_\mu = \pm 1$ depending on the polarity of the μth pulse in the sub-bit pattern.

B. Summary of Results

For convenience, the main equations resulting from the preceding derivation are summarized here. For $M(t)$ and $X(t)$ periodic

$$E_{FM}(\omega) = \delta(\omega-\omega_c) * S_1(\omega) * \left\{ S_2(\omega) + j\, M(\omega) * X(\omega) * S_3(\omega) \right\} \quad , \qquad (55)$$

where

$$S_1(\omega) = \sum_{n=-\infty}^{\infty} J_n(\lambda)[\cos(\lambda - \frac{n\pi}{2}) + j\sin(\lambda - \frac{n\pi}{2})]\, \delta(\omega - n\omega_1) \quad , \qquad (59)$$

$$S_2(\omega) = \sum_{n=-\infty}^{\infty} J_n(\frac{\lambda}{2})\cos(\frac{\lambda}{2} - \frac{n\pi}{2})\, \delta(\omega - 2n\omega_1) \quad , \qquad (62)$$

$$S_3(\omega) = \sum_{n=-\infty}^{\infty} J_n(\frac{\lambda}{2})\sin(\frac{\lambda}{2} - \frac{n\pi}{2})\, \delta(\omega - 2n\omega_1) \quad , \qquad (64)$$

$$M(\omega) = \sum_{n=-\infty}^{\infty} \frac{j[(-1)^n - 1]}{\pi n} \delta(\omega - n\omega_2) \quad , \tag{71}$$

and

$$X(\omega) = \sum_{n=-\infty}^{\infty} \left\{ \sum_{\mu=1}^{5} [I_\mu \cos(2\mu-1)\frac{n\pi}{5} - jI_\mu \sin(2\mu-1)\frac{n\pi}{5}] \right\} \frac{\sin \frac{n\pi}{5}}{\pi n} \delta(\omega - n\omega_3) \ . \tag{83}$$

C. Power Relationships

As an aid to monitoring the calculation, the theoretical power in each component part of the spectrum was calculated. For a periodic signal S(t), the power is given by

$$P_s = \frac{1}{T}\int_0^T |S^2(t)| \, dt \quad . \tag{84}$$

Applying this relationship to each signal component gives

Signal	Power
S_1	$P_1 = 1$
S_2	$P_2 = \frac{1}{2} + \frac{J_0(\lambda) \cos \lambda}{2}$
S_3	$P_3 = \frac{1}{2} - \frac{J_0(\lambda) \cos \lambda}{2}$
M	$P_M = 1$
X	$P_X = 1$ (85)

D. Computer Program

A Computer program, written in ALGOL compiler language for the Burroughs B 5500 computer, was constructed to evaluate the equations derived in Section V A and summarized in Section V B. The program is relatively straight forward and a listing of the program is given in Appendix A. A few comments about the program will be helpful in understanding it.

It was necessary that both phase and amplitude information be carried throughout the calculations. The method selected for doing this was to represent each spectral line coefficient as a complex number in the form x + jy.

For storage of the various spectra, a standard two dimensional array of dimensions 3 x n was adopted. These arrays are visualized as 3 columns (indexed 0, 1, and 2) and n lines (indexed 1 through n). For any given line, the 3 columns contain the frequency, real part of the coefficient and imaginary part of the coefficient. As an aid to certain manipulative operations, a line indexed zero was added. This line contained in the first column the number of lines reserved for the array, and in the second column the number of lines currently filled in the array. The third column was blank.

To facilitate the programming, a number of procedures were written. These included procedures to evaluate n!, $J_n(\lambda)$, convolve two arrays, sum two arrays, and a monitoring print procedure which could be called to print out the contents of an array. The convolution and sum procedures are designed to operate specifically on arrays of the form described above.

E. Results of Computations

Using the computer program, the output spectrum of the FM subcarrier generator was computed for $\lambda = 2.84$ and a sub-bit pattern of 1, -1, 1, -1, 1. The value of λ is that which corresponds to a 5 kHz peak deviation of the FM carrier when modulated by the baseband command data signal. The computed spectrum is shown in Figure 11.

It is of interest that with the alternating sub-bit pattern used for X(t) and with the alternating bit pattern used for M(t), the resulting biphase modulation is a square wave with a fundamental frequency of 500 Hz. The spectrum for this modulation should contain no components at spacings less than 500 Hz, even though both the M and X function do contain components with 200 Hz spacing. The coefficients of lines at other than 500 Hz spacing should sum to zero, and this does occur as can be seen in Figure 11.

As a check on the accuracy of the prediction technique, the predicted values were compared with measured values obtained from a laboratory version of the circuit. To effect the laboratory set-up, a breadboard model of the biphase modulator was constructed. This model was then used to frequency modulate a carrier and the output spectrum was displayed on a spectrum analyzer and photographed. Measurements taken from the photograph were then compared with the predicted values.

Figure 12(a) shows the time waveform of the total signal out of

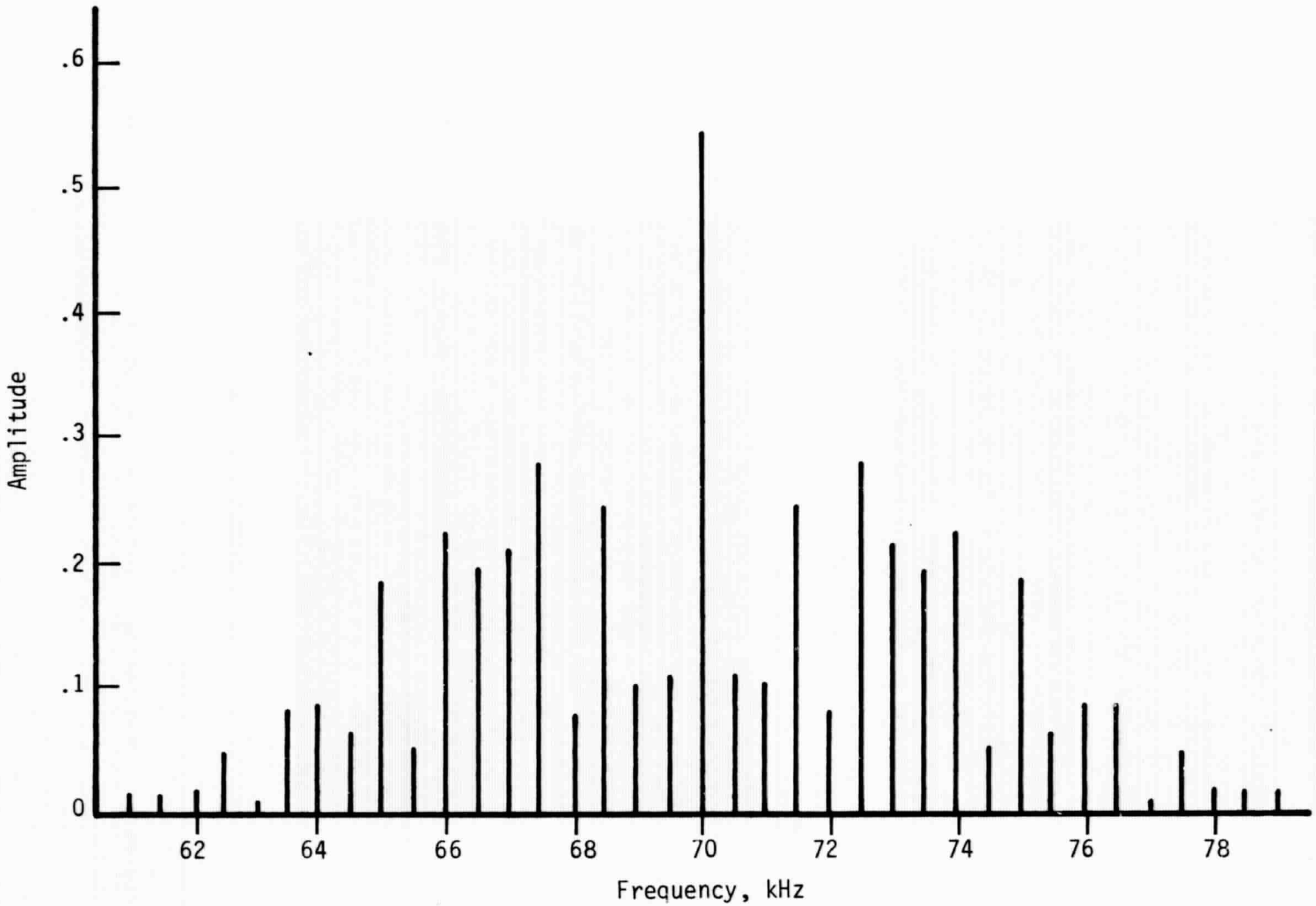
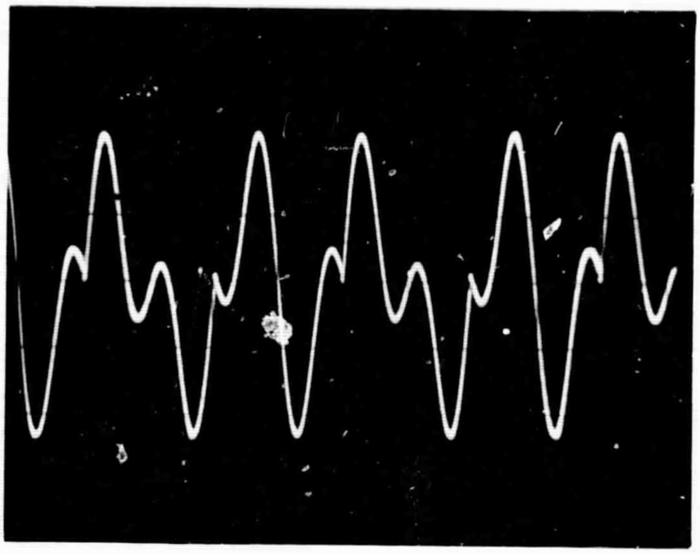
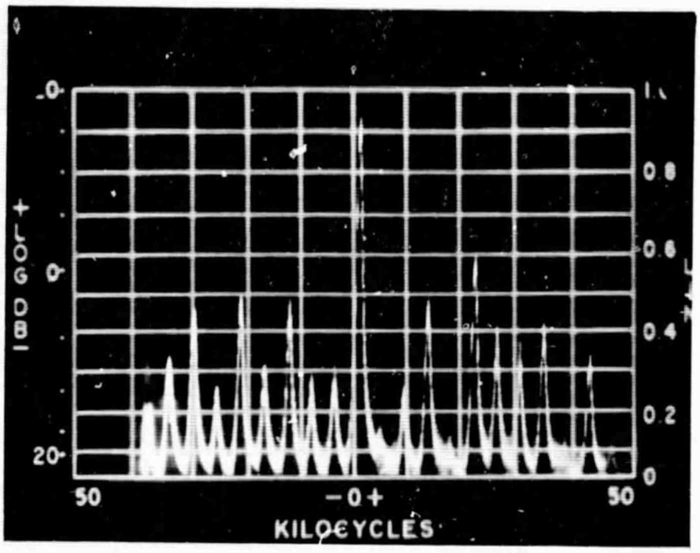


Figure 11. Computed FM spectrum for λ = 2.84 (5 kHz peak deviation), sub-bit pattern 1, -1, 1, -1, 1.



(a) Modulating Waveform



(b) Output Spectrum

Figure 12. Modulating waveform and output spectrum of the FM subcarrier oscillator.

the biphase modulator. This signal consists of (1) the sum of a 2 kHz sinewave which is biphase modulated over a total phase angle of π radians at a frequency 500 Hz, and (2) a 1 kHz sinewave. The two sinewaves were combined with equal amplitudes and the peak amplitude of the composite waveform was adjusted to give a peak deviation of the FM carrier of 5 kHz. The biphase modulator actually had a small error in its switching angles as evidenced by the small discontinuities at the switching points shown in Figure 12(a).

The actual photograph of the output FM spectrum, Figure 12(b), shows the amplitude spectrum on a linear scale. The slight asymmetry of the pattern is attributed to the switching errors mentioned above. Although the appearance of the spectrum on the photograph shows good agreement with the predicted spectrum, a better comparison was achieved by taking readings from the photograph and plotting them to the same scale as that used to plot the predicted spectra. The measured values were normalized to the computed values by adjusting the measured carrier until it equaled the predicted values. All other measured values were scaled proportionately. These measured values along with the predicted values are shown in Figure 13.

Some additional computational runs were made with the FM spectrum program to study certain variational effects. On one of these runs the spectrum was computed for the same value of λ (= 2.84) but for a sub-bit pattern of 1, 1, 1, -1, -1. Note that since the bit pattern alternates, this sub-bit pattern should also produce squarewave modulation. The fundamental frequency in this case is 100 Hz rather than 500 Hz since each half cycle of the modulating square wave is 5 milliseconds long. The computed spectrum is shown in Figure 14 and contains lines whose spacing is less than 500 Hz.

A comparison of the two spectra shown in Figures 11 and 14 reveals that the spectral lines at multiples of 1 kHz are unaffected by the change in the sub-bit pattern. Those lines which occurred at odd multiples of 500 Hz in Figure 11 are reduced in amplitude in Figure 14. It appears that the energy which was formerly contained in these lines has been dispersed into several lines whose frequencies differ by 100, 300, 500, 700, and 900 Hz from multiples of 1 kHz.

Note in comparing Figures 11 and 14 that the overall spread of the spectrum has not been significantly changed. The envelopes of the two spectra are almost identical. This suggests that the same bandwidth would be required to pass each of the two spectra.

Another effect studied by means of the computer program was that of varying the peak deviation of the frequency modulated signal. The output spectra was computed for peak deviations of 4.0, 4.5, 5.5, and 6.0 kHz (λ = 2.275, 2.557, 3.125, and 3.409) for comparison with the spectrum for 5.0 kHz deviation. All of these spectra were computed for

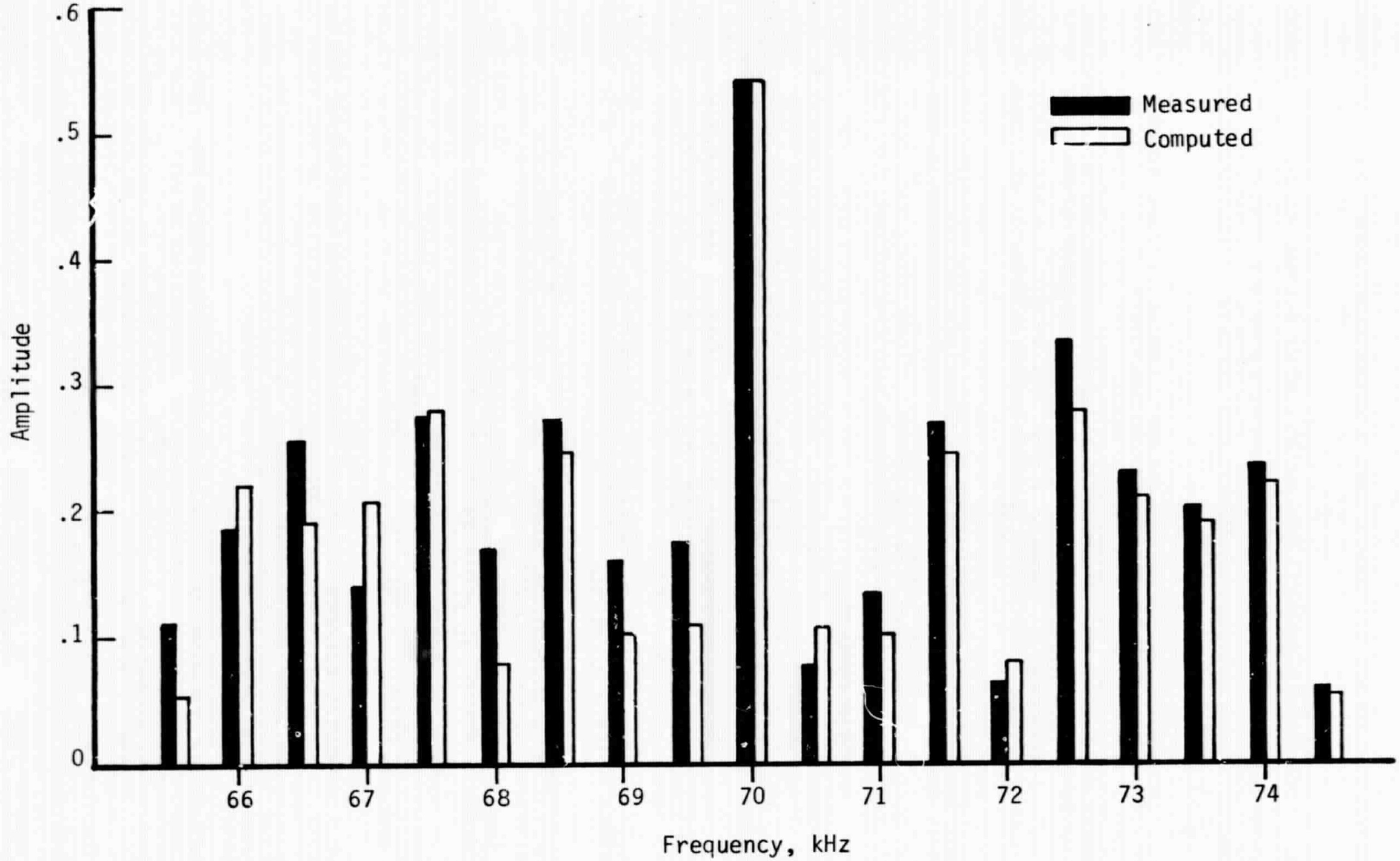


Figure 13. Comparison of measured vs computed FM spectra $\lambda = 2.84$ (5 kHz peak deviation), sub-bit pattern 1, -1, 1, -1, 1.

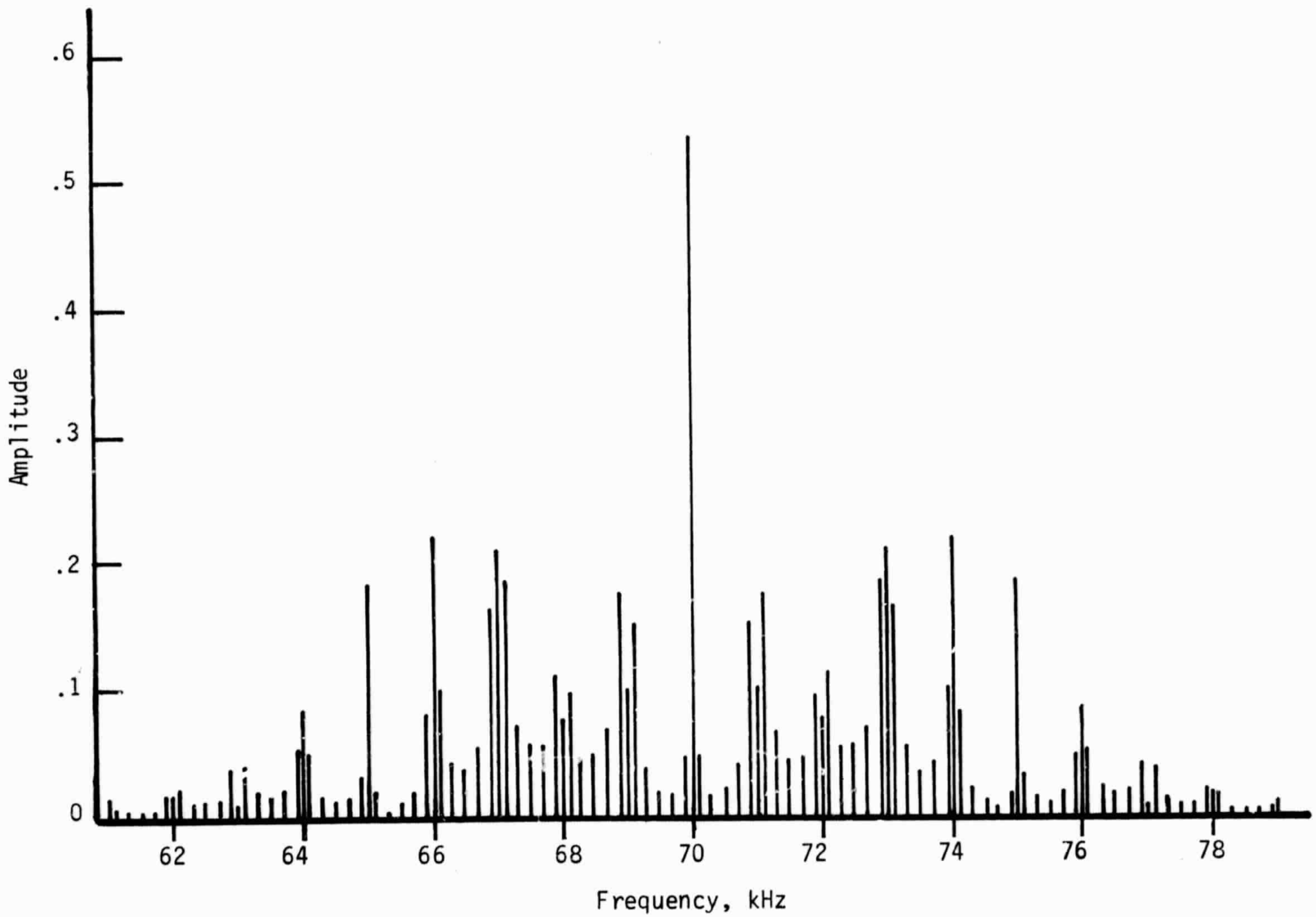


Figure 14. Computed FM spectrum for $\lambda = 2.84$ (5 kHz peak deviation), sub-bit pattern 1, 1, 1, -1, -1.

alternating sub-bits, and graphs of the spectra are shown in Figure 15 - 18. All of these spectra produce lines at 500 kHz spacing. In general they show a gradual widening of the spectrum as the peak deviation is increased, as evidenced by more energy appearing in sidebands that are farther removed from the carrier.

Laboratory measurements of the output were made for peak deviations of 4.0 and 4.5 kHz. Photographs of the oscilloscope display are shown in Figures 19 and 20. Using the same procedure previously discussed, measurements were taken from these two photographs and comparative graphs of the computed and measured spectrum were made for each of these deviations. These graphs are shown in Figures 21 and 22.

The output spectra for the two wider deviations (5.5 and 6.0 kHz) were not measured since it would have been necessary to increase the driving voltage into the modulator to well above the specified maximum of 5.0 volts peak-to-peak. Actually, it was necessary to exceed this figure slightly in order to get a peak deviation of 5.0 kHz. Tests showed that a modulating signal of 5.35 volts peak-to-peak was required to give a peak deviation of 5.0 kHz.

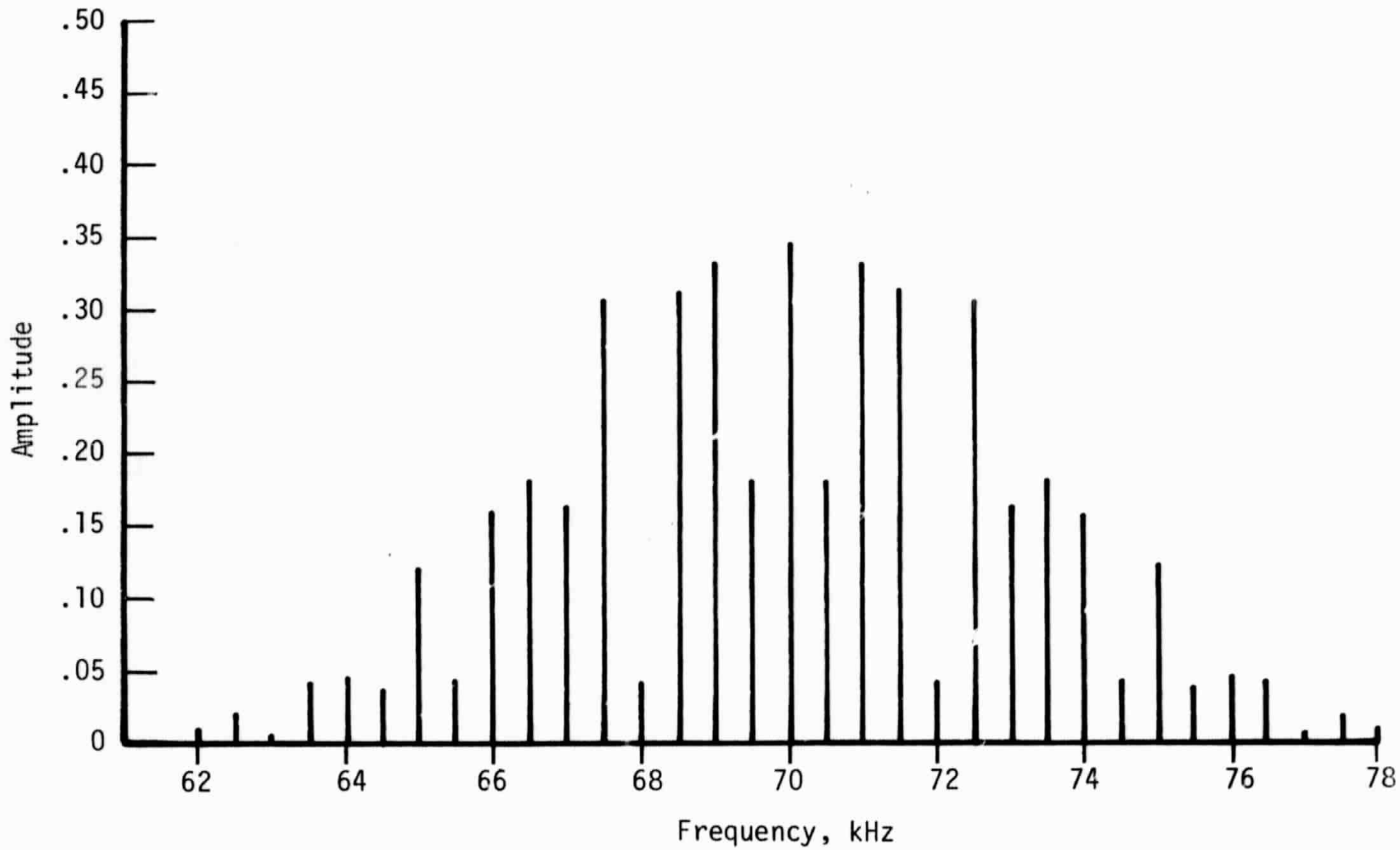


Figure 15. Computed FM spectrum for $\lambda = 2.275$ (4.0 kHz peak deviation), sub-bit pattern 1, -1, 1, -1, 1.

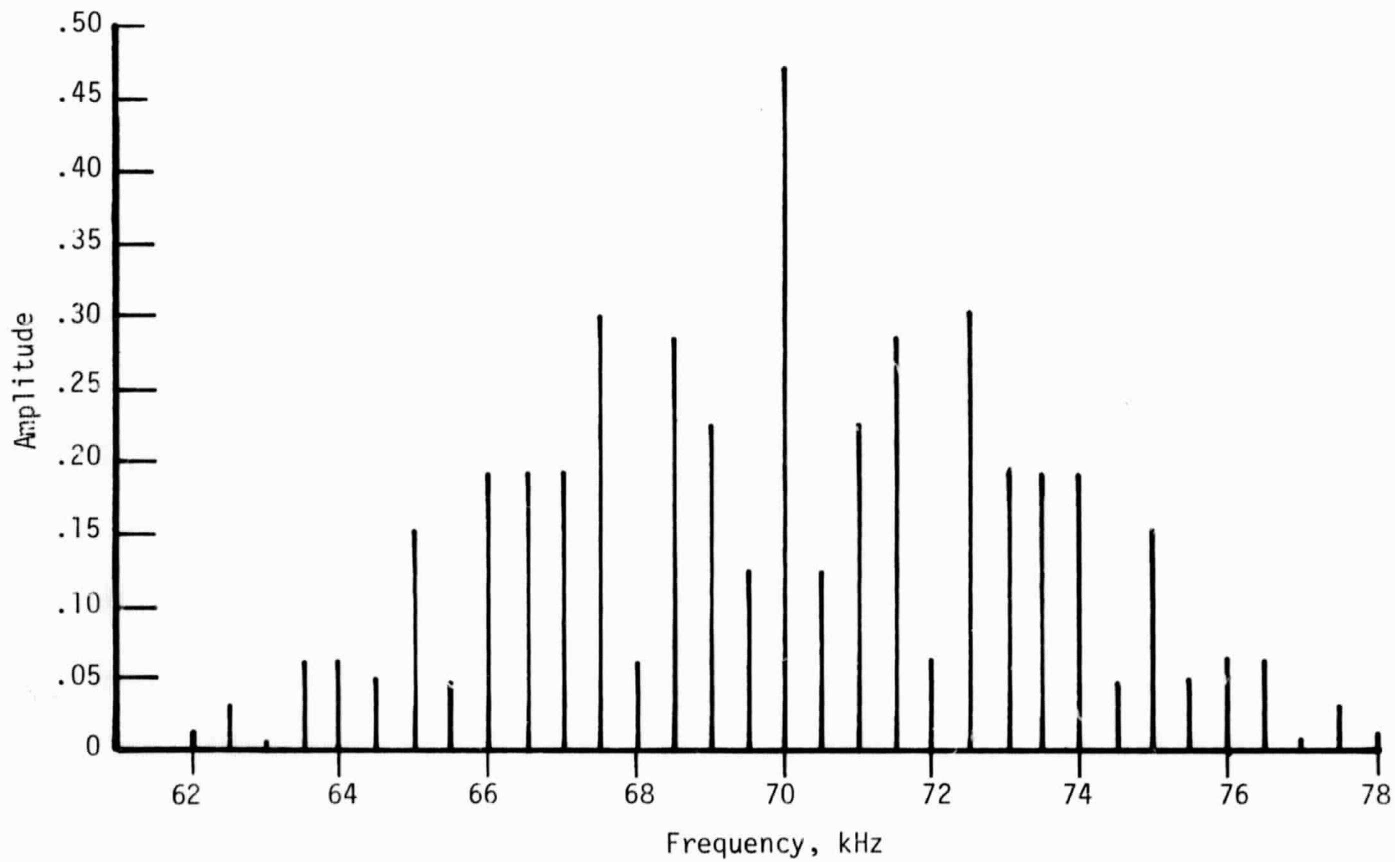


Figure 16. Computed FM spectrum for λ = 2.557 (4.5 kHz peak deviation), sub-bit pattern 1, -1, 1, -1, 1.

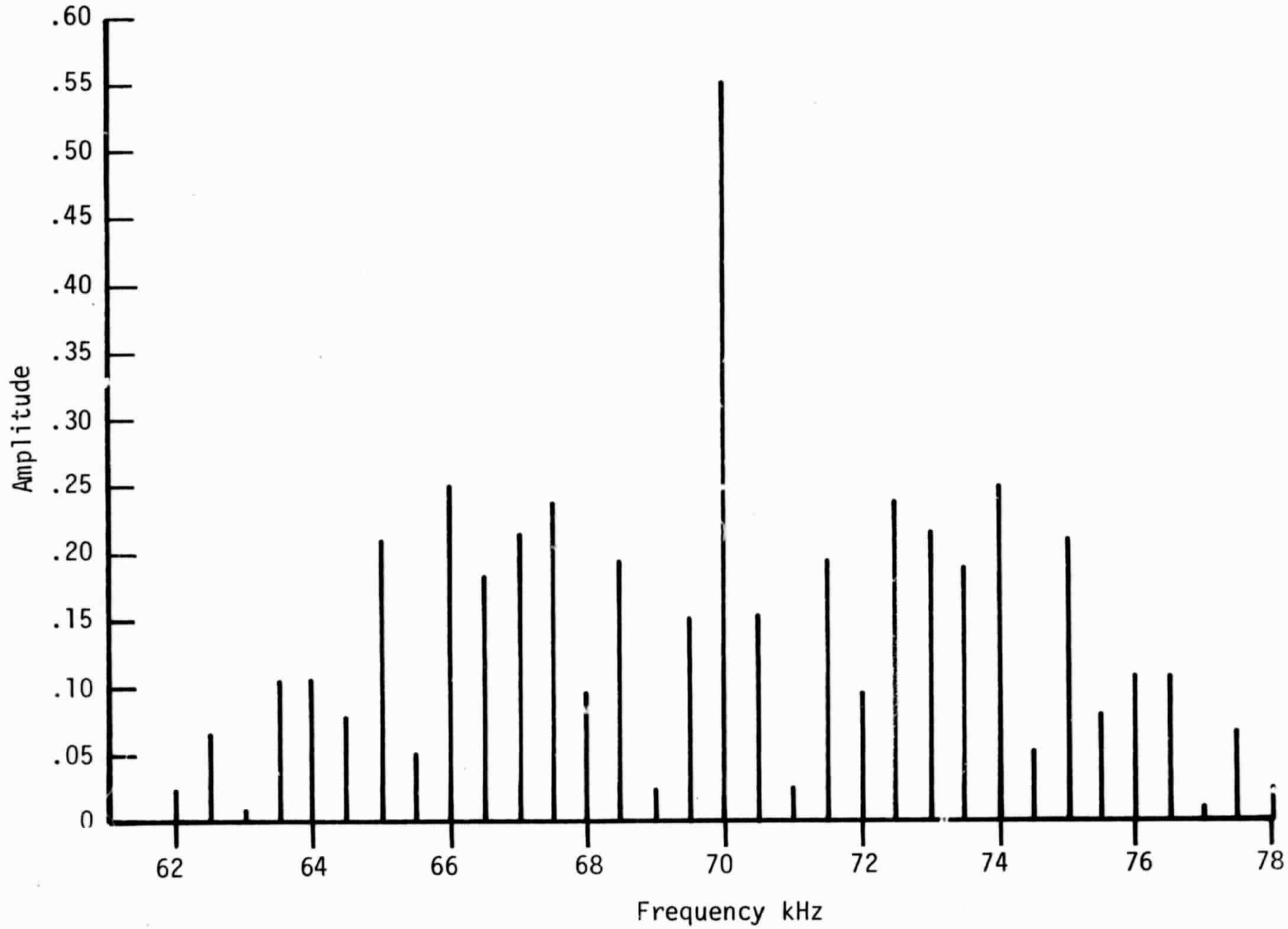


Figure 17. Computed FM spectrum for $\lambda = 3.125$ (5.5 kHz peak deviation), sub bit pattern 1, -1, 1, -1, 1.

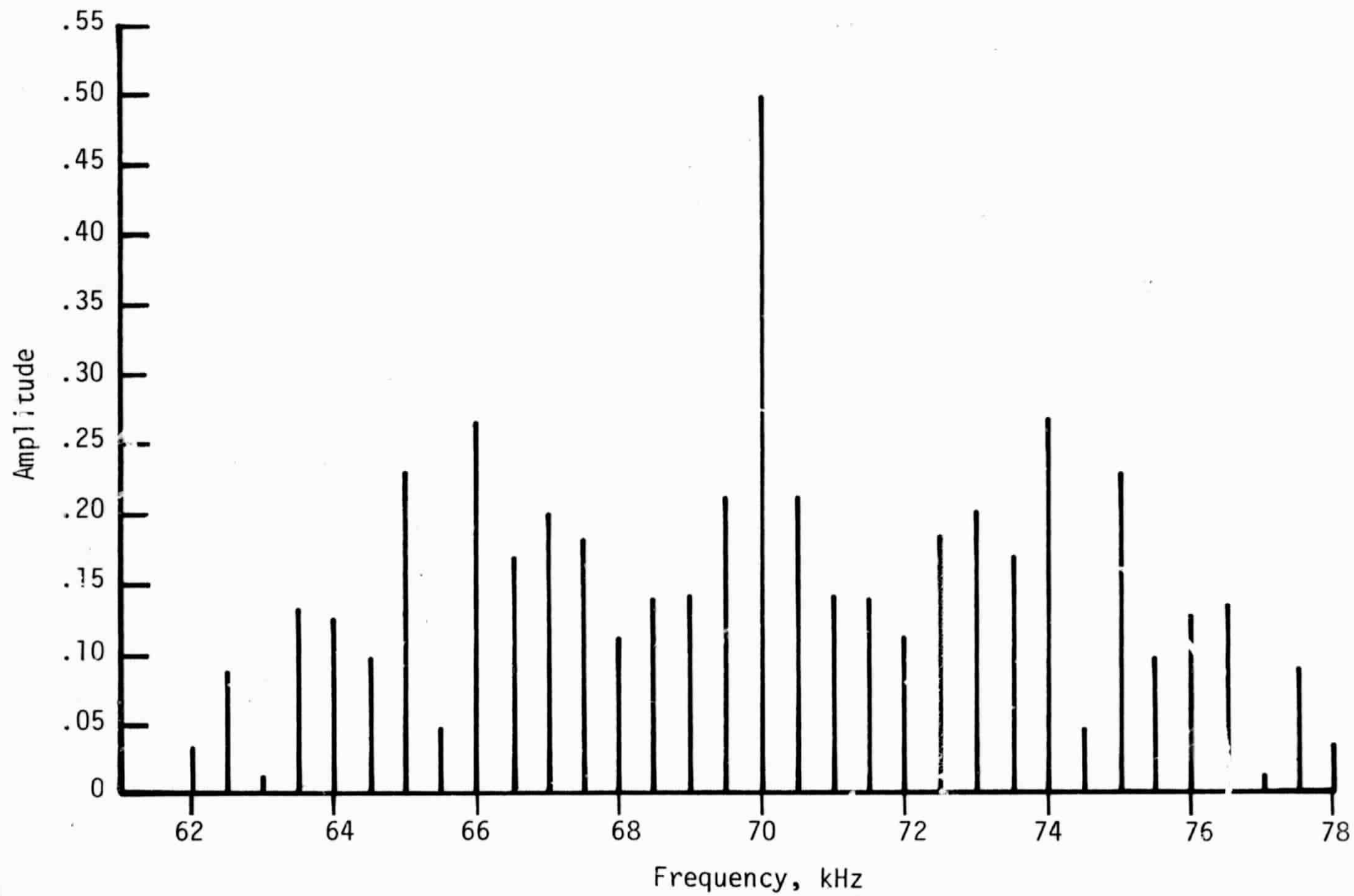


Figure 18. Computed FM spectrum for λ = 3.409 (6.0 kHz peak deviation), sub-bit pattern 1, -1, 1, -1, 1.

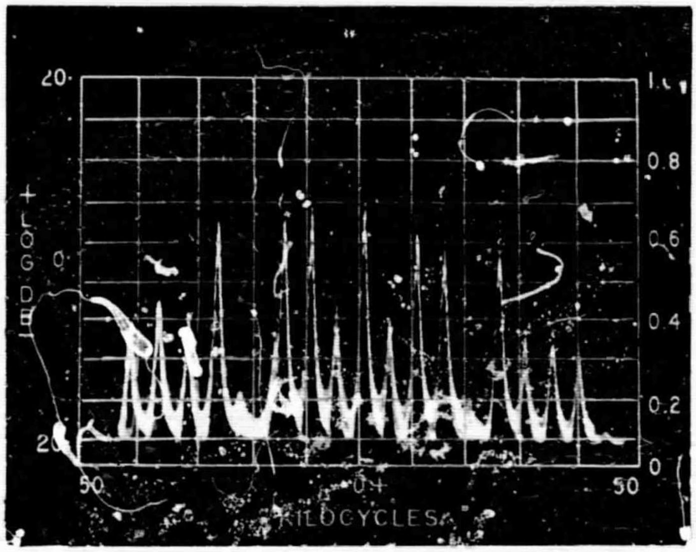


Figure 19. Output spectrum of FM subcarrier generator for a peak deviation of 4.0 kHz.

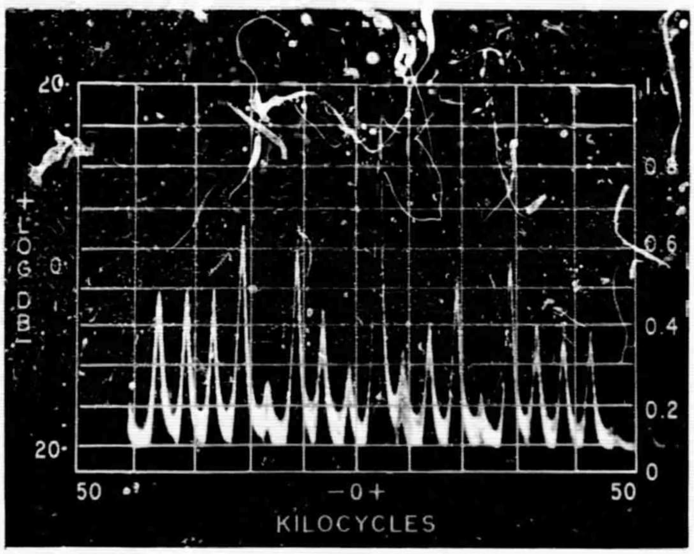


Figure 20. Output spectrum of FM subcarrier generator for a peak deviation of 4.5 kHz.

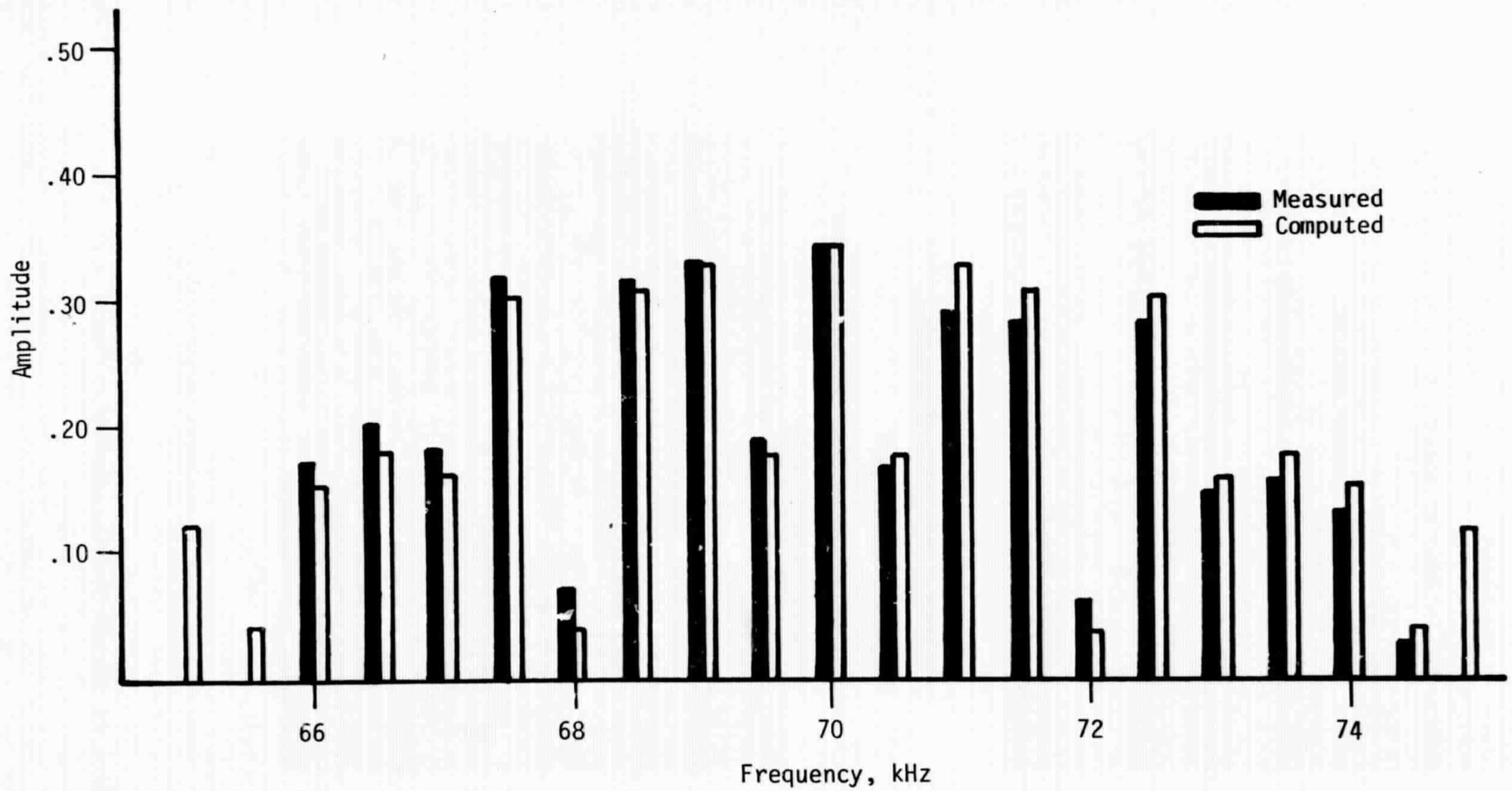


Figure 21. Measured vs computed FM spectra for a peak deviation of 4.0 kHz.

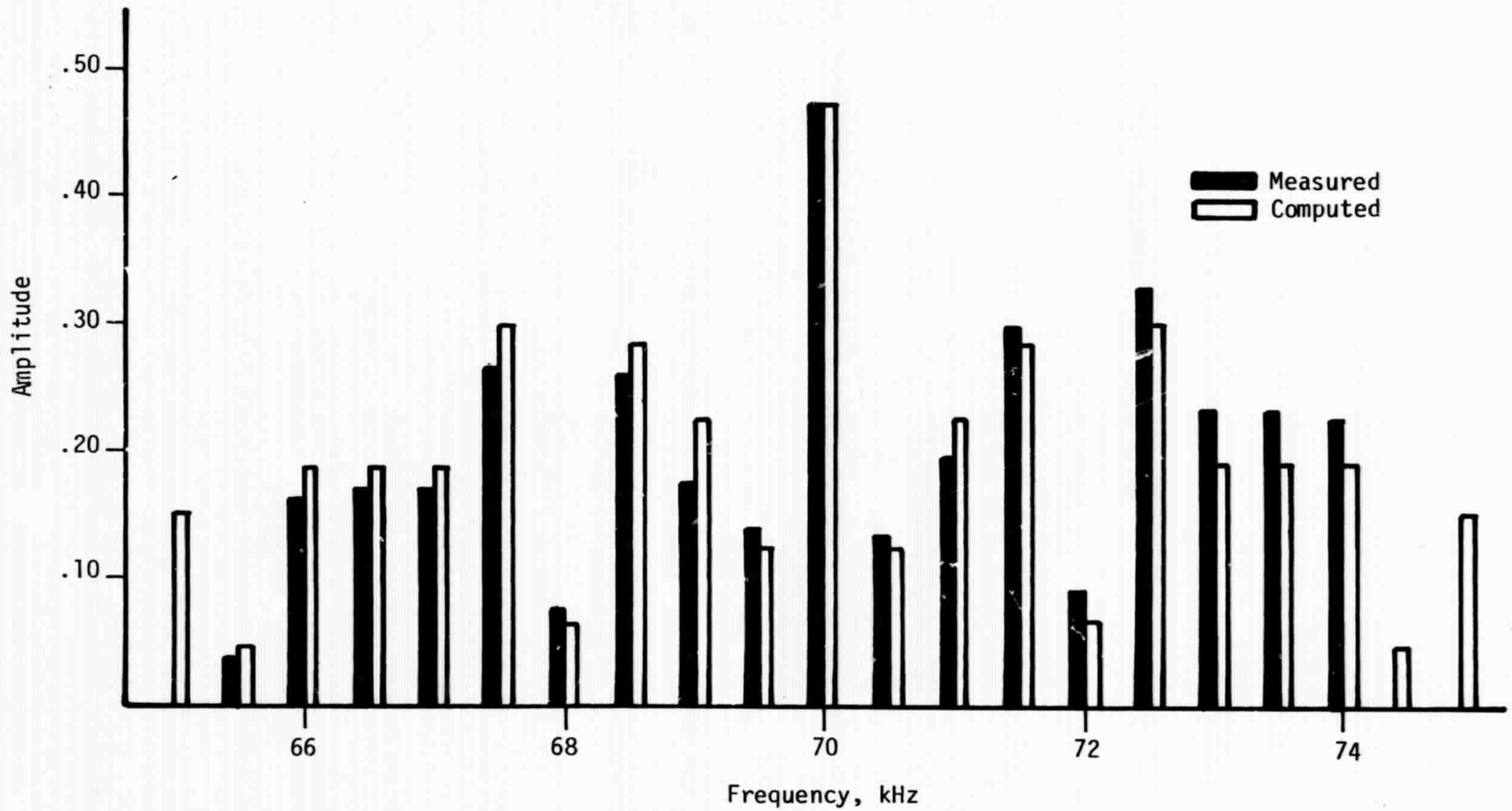


Figure 22. Measured vs computed FM spectra for a peak deviation of 4.5 kHz.

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VI. S-BAND SPECTRUM

A. General Approach

The output of the FM modulated subcarrier oscillator is phase modulated onto the S-band carrier. Before being applied to the S-band transmitter, however, it is summed with the range data code (a stream of digital data) when this code is present. Consequently the output S-band signal is the result of these two modulating signals. The range data code will probably be generated only part of the time, hence the modulating signal applied to the S-band transmitter is at times only the output of the FM subcarrier oscillator, while at other times the modulating signal is the oscillator output plus a stream of digital data made up of pseudo noise sequences.

Although it is possible to derive mathematical expressions for the spectrum at the S-band output, there are practical problems involved in calculating the spectrum due to the large number of lines involved. General consideration of the two signals modulating the S-band transmitter indicate that the command data alone will produce a spectrum with line spacings as small as 100 Hz, while the range data alone will produce lines at wider spacings which spread over several Megahertz. The interaction of these two will produce a spectrum several Megahertz wide with lines at 100 Hz spacing. Calculating the tens of thousands of lines in a sample spectrum (for fixed command data code and fixed range data code) would tax the capabilities of the largest computers. Also it is somewhat doubtful if the fine detail in the entire spectrum would really provide any useful information.

As a method of approach in analyzing the S-band spectrum, the problem was divided into three sub-problems. First, the S-band spectrum for the command data alone was calculated. Second, the S-band spectrum due to the range data alone was computed. Finally, the spectrum produced when both signals modulated the S-band transmitter was computed, but with the input from the command data channel being limited to the unmodulated subcarrier. By considering the subcarrier without modulation, the close spacing of spectral lines that was caused by the command data modulation was eliminated. Although neither of the three types of calculations that were made produced the output spectrum in its entirety, the results of the calculations do permit determination of the nature of the S-band spectrum. Details of the analysis of each of these three subproblems and the calculations of the spectra are discussed in the follow- sections.

B. S-Band Spectrum of the Command Data

1. Derivation of Equations

It is not difficult to derive an expression for the S-band spectrum resulting from the command data modulation and several such derivations were made; the problem lies in obtaining an expression that lends itself to computation. Some insight into the problem might be gained by considering the nature of the spectrum in a qualitative manner.

Assume that the subcarrier oscillator were not modulated. Its output would simply be the 70 kHz subcarrier. Phase modulating the S-band transmitter with this signal would produce an output spectrum consisting of a set of spectral lines spaced at 70 kHz about the S-band carrier. This spectrum is easy to derive since it is simply single-tone phase modulation.

When the subcarrier oscillator is being frequency modulated, the input signal modulating the S-band transmitter is the set of frequencies described by the subcarrier oscillator's FM spectrum. This spectrum consists of a group of lines centered about 70 kHz and a similar group centered about -70 kHz. The output S-band spectrum will consist not of a single line at each multiple of 70 kHz, but a group of lines centered about each of these frequencies. It can be shown that each side band group is described by the (n-1) - fold convolution of the input FM spectrum with itself. Such a derivation provides a mathematical expression for the spectrum, but carrying out the calculations presents a formidable task even on a high speed computer.

A method of describing the spectrum which does make the calculation of the spectral components practical was developed and is described in the following paragraphs.

If the signal out of the subcarrier oscillator is $e_{FM}(t)$, then the signal out of the S-band transmitter is

$$e_{PM}(t) = \cos[\omega_s t + \beta_1 e_{FM}(t)]$$

$$= \frac{1}{2} e^{j\omega_s t} e^{j\beta_1 e_{FM}(t)} + \frac{1}{2} e^{-j\omega_s t} e^{-j\beta_1 e_{FM}(t)} \quad , \qquad (86)$$

where ω_s is the S-band carrier frequency and β_1 is the modulation index.

Let

$$h(t) = e^{j\beta_1 e_{FM}(t)} \quad . \tag{87}$$

The portion of the spectrum of $e_{PM}(t)$ in the positive ω region is then

$$E_{PM}(\omega) = \frac{1}{2}\,\delta(\omega - \omega_s) * H(\omega) \quad , \tag{88}$$

where

$$H(\omega) = \mathscr{F}\,[h(t)] \quad . \tag{89}$$

But

$$h(t) = e^{j\beta_1 e_{FM}(t)} \quad ,$$

$$= \sum_{n=0}^{\infty} \frac{(j)^n \beta_1^{\,n}}{n!}\, e_{FM}^n(t) \quad , \tag{90}$$

and

$$e_{FM}^n(t) = \frac{1}{2^n}\left[e^{j\omega_c t}\, e^{jf(t)} + e^{-j\omega_c t}\, e^{-jf(t)}\right]^n$$

$$= \frac{1}{2^n} \sum_{r=0}^{n} C_r^n\, e^{j(n - 2r)\omega_c t}\, e^{j(n - 2r)f(t)} \quad , \tag{91}$$

where ω_c is the subcarrier frequency and

$$C_r^n = \frac{n!}{r!\,(n-r)!} \quad . \tag{92}$$

Also from equations (39), (40), (41), and (42)

$$f(t) = \lambda[\varphi_1(t) + \frac{1}{2}M(t)\, X(t)\, \varphi_2(t)] \tag{93}$$

is the modulation applied to ω_c. Substituting from Equation (91) into (90) gives

$$h(t) = \sum_{n=0}^{\infty} \sum_{r=0}^{\infty} \frac{(j)^n \beta_1^{\ n}}{n!2^n} C_r^n\, e^{j(n-2r)\omega_c t}\, e^{j(n-2r)f(t)} \quad . \tag{94}$$

Let q = n - 2r. Then

$$h(t) = \sum_{q=-\infty}^{\infty} \sum_{n=|q|}^{\infty} \frac{(j)^n \beta_1^{\ n}}{n!2^n}\, C^n_{\frac{n-q}{2}}\, e^{jq\omega_c t}\, e^{jqf(t)} \quad , \tag{95}$$

and

$$H(\omega) = \mathfrak{F}[h(t)]$$

$$= \sum_{q=-\infty}^{\infty} \sum_{n=|q|}^{\infty} \frac{(j)^n \beta_1^{\ n}}{n!2^n}\, C^n_{\frac{n-q}{2}}\, \delta(\omega - q\omega_c) * \mathfrak{F}[e^{jqf(t)}] \quad . \tag{96}$$

Since

$$F(\omega,\lambda) = \mathfrak{F}[e^{jf(t)}] \quad , \tag{97}$$

where f(t) is defined in Equation (93), then

$$F(\omega,q\lambda) = \mathcal{F}[e^{jqf(t)}] \quad , \tag{98}$$

where

$$qf(t) = q\lambda[\varphi_1(t) + \frac{1}{2} M(t)\, X(t)\, \varphi_2(t)] \quad . \tag{99}$$

Hence

$$H(\omega) = \sum_{q=-\infty}^{\infty} \sum_{n=|q|}^{\infty} \frac{(j)^n \beta_1^{\ n}}{n!2^n} C^n_{\frac{n-q}{2}} \delta(\omega - q\omega_c) * F(\omega,q\lambda) \quad . \tag{100}$$

Equation (100) provides a method of computing the qth sideband group by computing the FM spectrum for a modulation index of $q\lambda$, rather than making (q-1) convolutions of the FM spectrum computed for modulation index λ. The resulting spectrum, $H(\omega)$, distributed about the carrier in the positive ω region can then be combined with the S-band carrier by means of Equation (88). It can be shown that $|H(\omega)|$ is an even function of ω, while the argument of $H(\omega)$ is an odd function of ω. Thus the amplitude spectrum will be symmetrical about the S-band carrier, although matching components on opposite sides of the carrier will be out of phase.

2. Computer Program

A computer program was constructed for computing the S-band spectrum with only the sub-carrier oscillator output, $e_{FM}(t)$, as input to the phase modulator; the range data code was not included. The program is given in Appendix B and is largely adapted from the FM program since the major part of the computation required is the evaluation of the FM spectrum, $F(\omega,q\lambda)$, in Equation (100). Following the computation of $F(\omega,q\lambda)$, the quantity $H(\omega)$ is calculated and then E_{PM} formed by Equation (88).

For this program, the separate spectra $M(\omega)$ and $X(\omega)$ for the bit switching rate and sub-bit switching rate were combined into a single spectrum (identified in the program as M). This spectrum was computed for alternating sub-bits hence the spectral lines have a minimum spacing of 500 Hz. This change was made to reduce the number of spectral components involved in the calculation, since the number of lines in the S-band spectrum is large even for alternating sub-bits. Also the investigation made in the FM spectrum studies showed that the overall envelope was not affected by variation of the sub-bit pattern.

The program computes the components of one sideband group at a time. That is, those spectral components in the neighborhood of $(\omega_s + \omega_c)$ are computed first (after computing the magnitude of the S-band carrier) and printed out. Next the components about $(\omega_s + 2\omega_c)$ are computed and printed out, etc. Fortunately the lines within each sideband group drop off fast enough so that over-lap between the groups did not have to be considered.

3. Results of Comp[illegible]

The program described in the preceding section was run to obtain the S-band spectrum (range data code not considered) for alternating sub-bits. The resulting spectrum contains so many components at 500 Hz spacing and is spread over such a wide range that it was not feasible to present it on one graph. The spectrum can reasonably be presented in a series of graphs, however.

Figure 23 shows a curve which passes through the highest line in each subgroup. Thus this curve is an envelope of the entire spectrum. To examine what the groups themselves look like, the first five sideband groups are shown in Figures 24 through 28. In all six of the figures, the amplitude of the components are shown in dB relative to the carrier level with the modulation applied.

As a check on the calculations, laboratory measurements of the S-band spectrum were made. Using the laboratory biphase modulator, the input signal to the subcarrier oscillator was developed and used to frequency modulate a 70 kHz oscillator, with the modulation adjusted to give a peak deviation of 5 kHz. The output of this oscillator was used to phase modulate the S-band signal generator contained in the Interstate equipment. The modulation was adjusted to give a peak deviation of 1.22 radians.

The time waveform of the signal into the subcarrier oscillator is shown in Figure 29, and the output S-band spectrum is shown in Figure 30 with a horizontal scale of 100 kHz/cm. and a vertical scale of 10 dB/cm. Peak values of the first four sidebands were read from this photograph and plotted on Figure 23. The first three sideband levels show good agreement with the theoretical values. The fourth level differs somewhat, and this difference is probably due to limitations in the laboratory equipment. Note in Figure 30 that the fourth sideband group is so near the noise level that determination of its level is probably subject to appreciable error.

To examine the detailed nature of the sideband, the horizontal sweep was expanded to 10 kHz/cm. and each of the first three sideband groups were photographed separately. The three sidebands below the carrier are shown in Figure 31, and the same three above the carrier are shown in

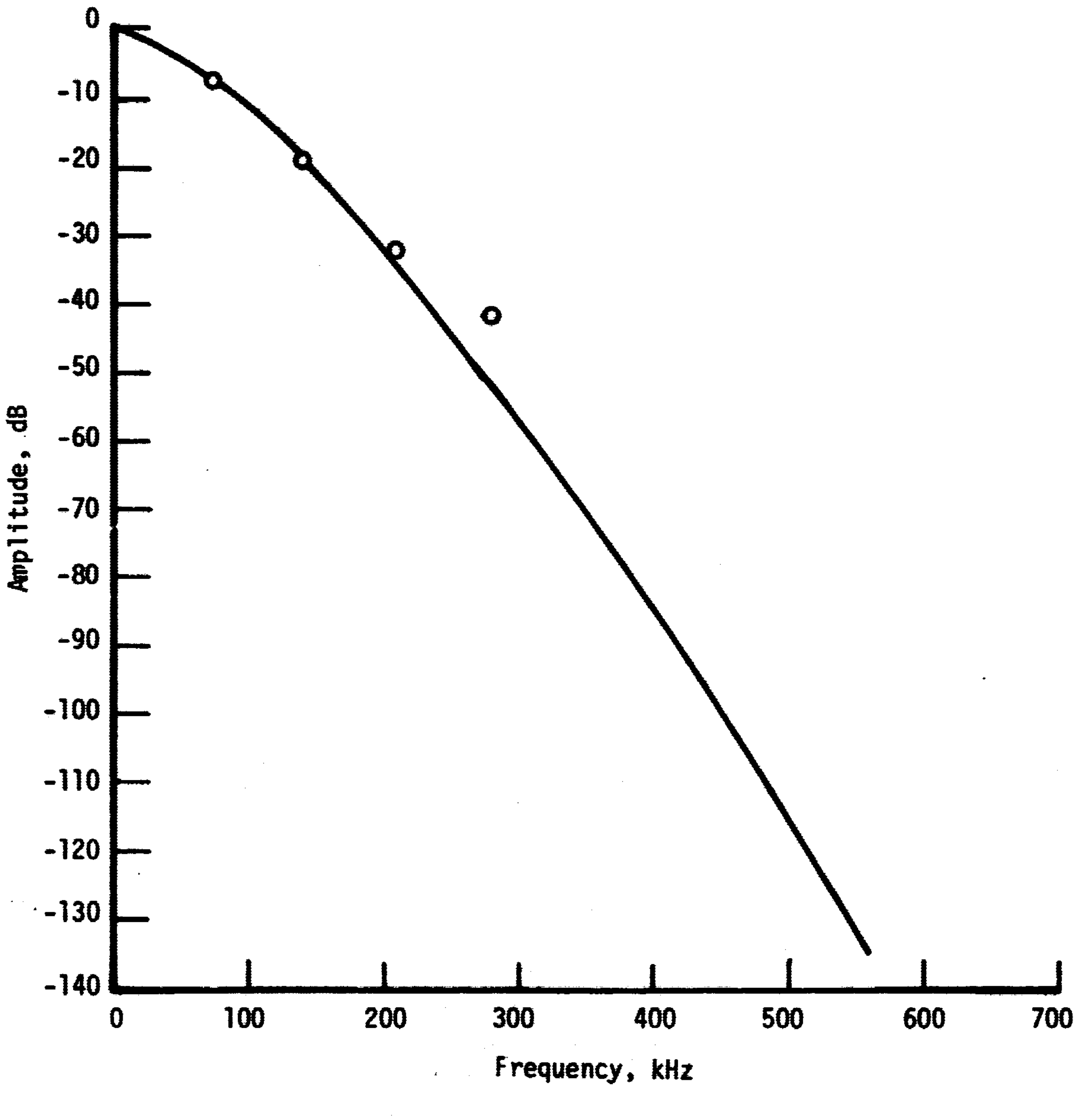


Figure 23. Envelope of sidebands of S-band spectrum for command data modulation.

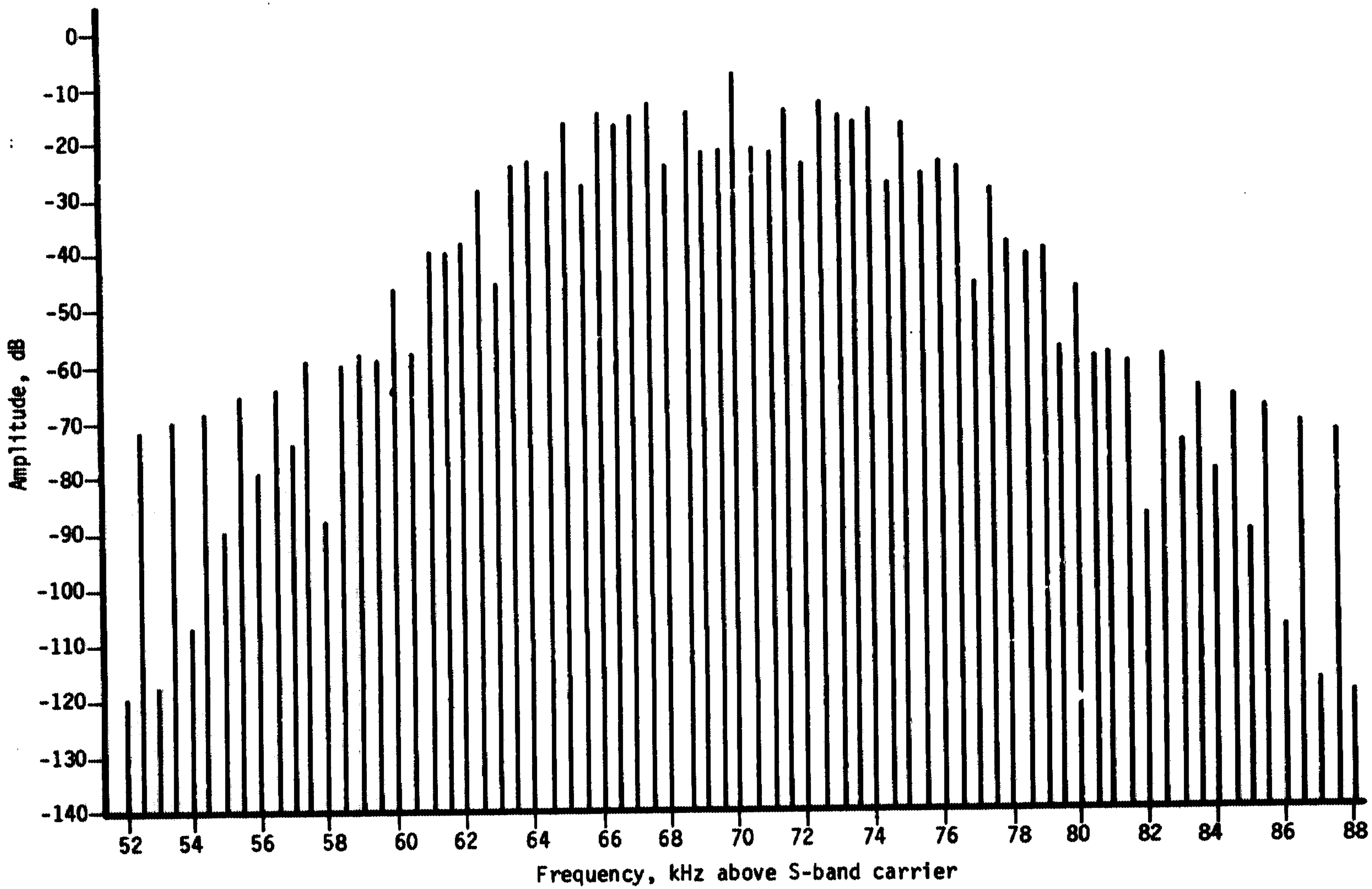


Figure 24. First sideband group of S-band spectrum for command data modulation.

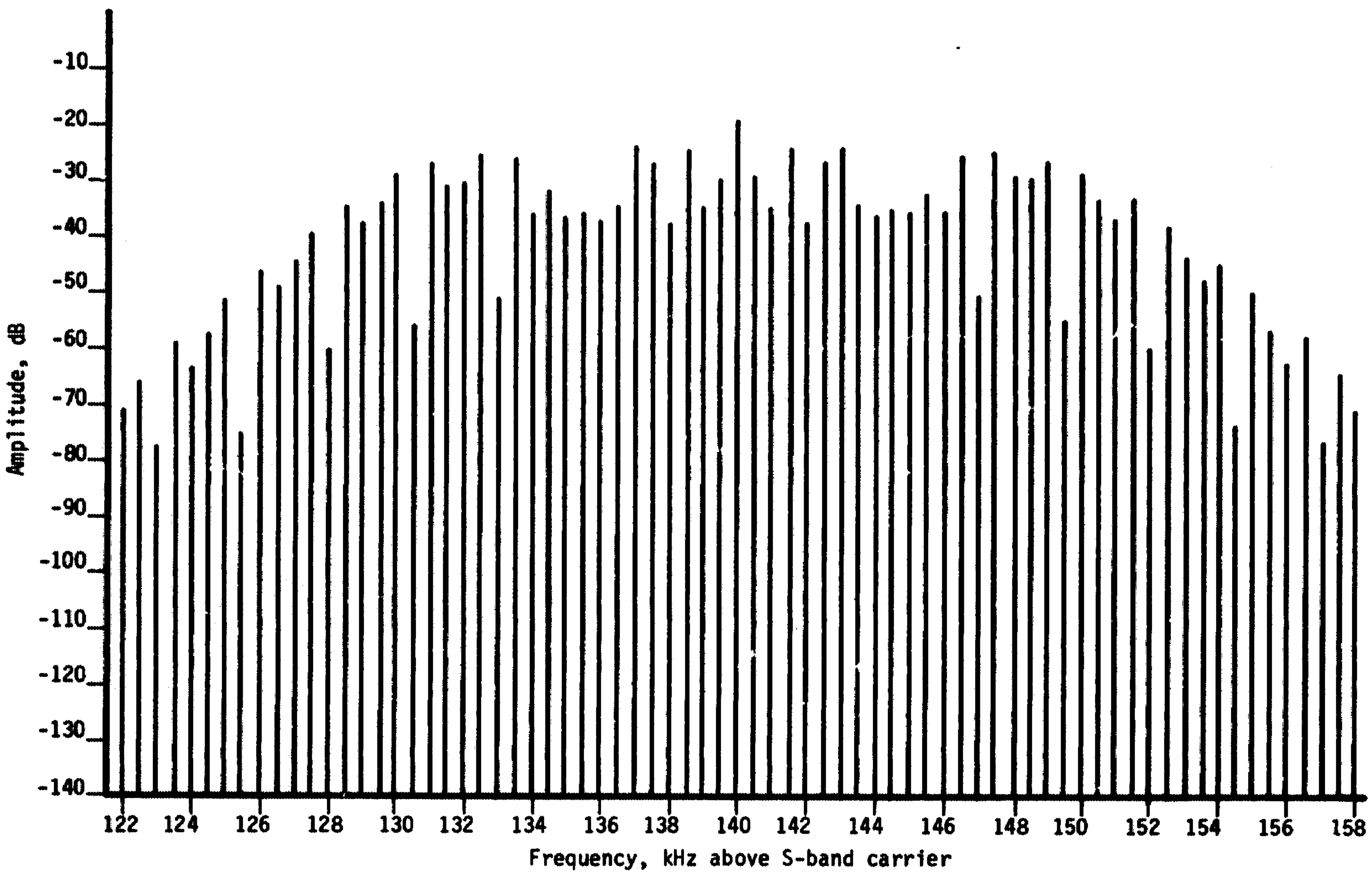


Figure 25. Second sideband group of S-band spectrum for command data modulation.

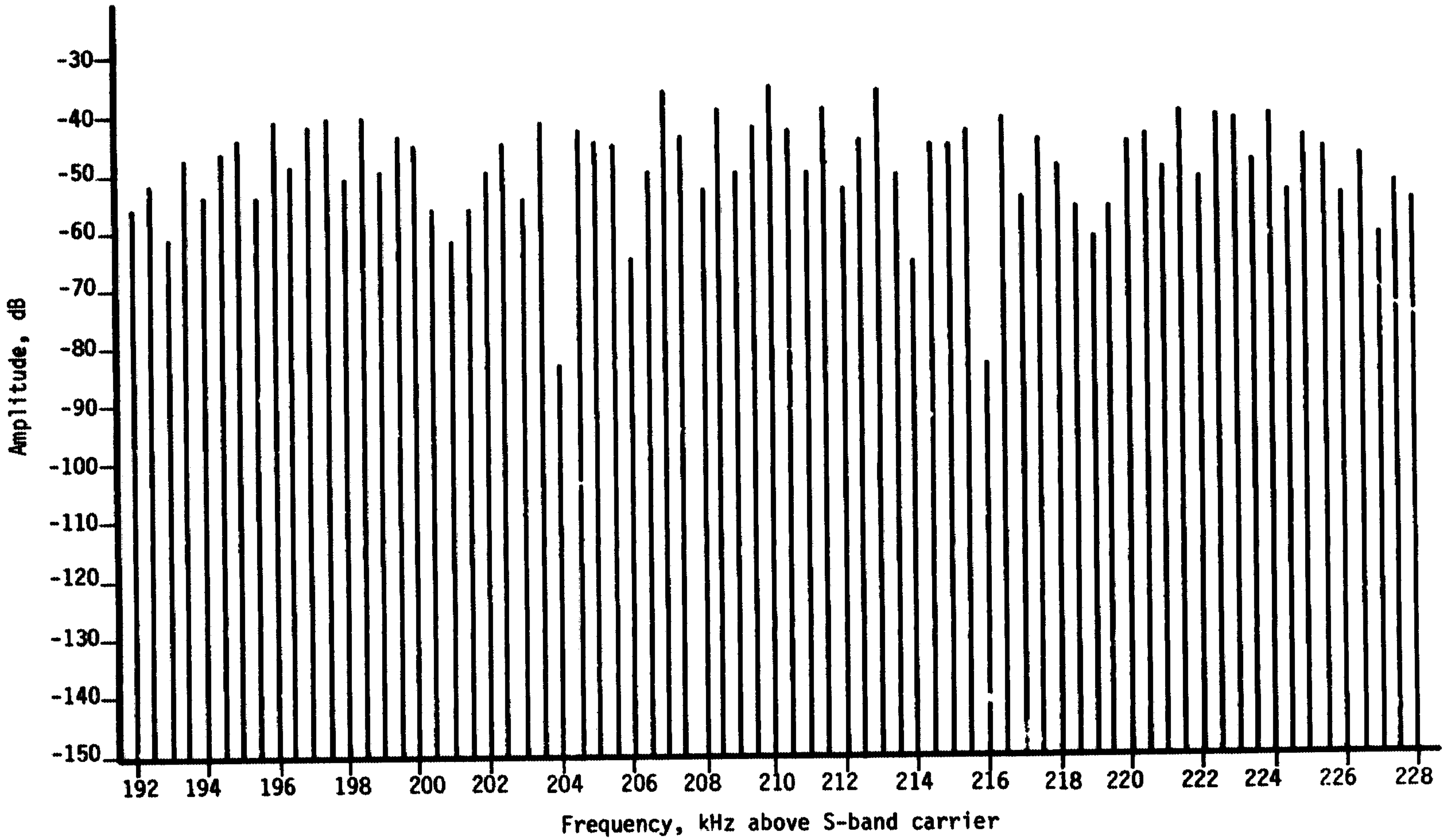


Figure 26. Third sideband group of S-band spectrum for command data modulation.

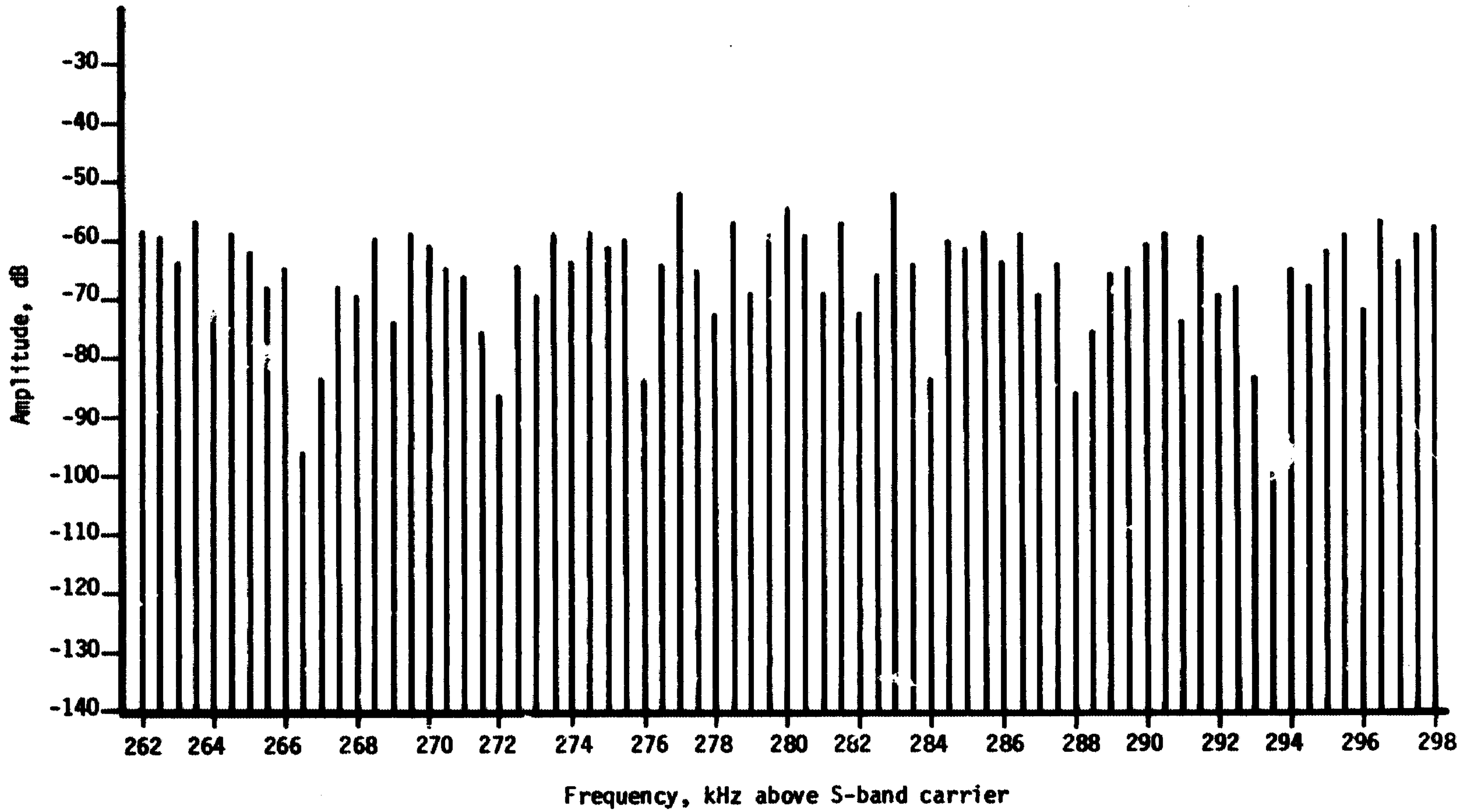


Figure 27. Fourth sideband group of S-band spectrum for command data modulation.

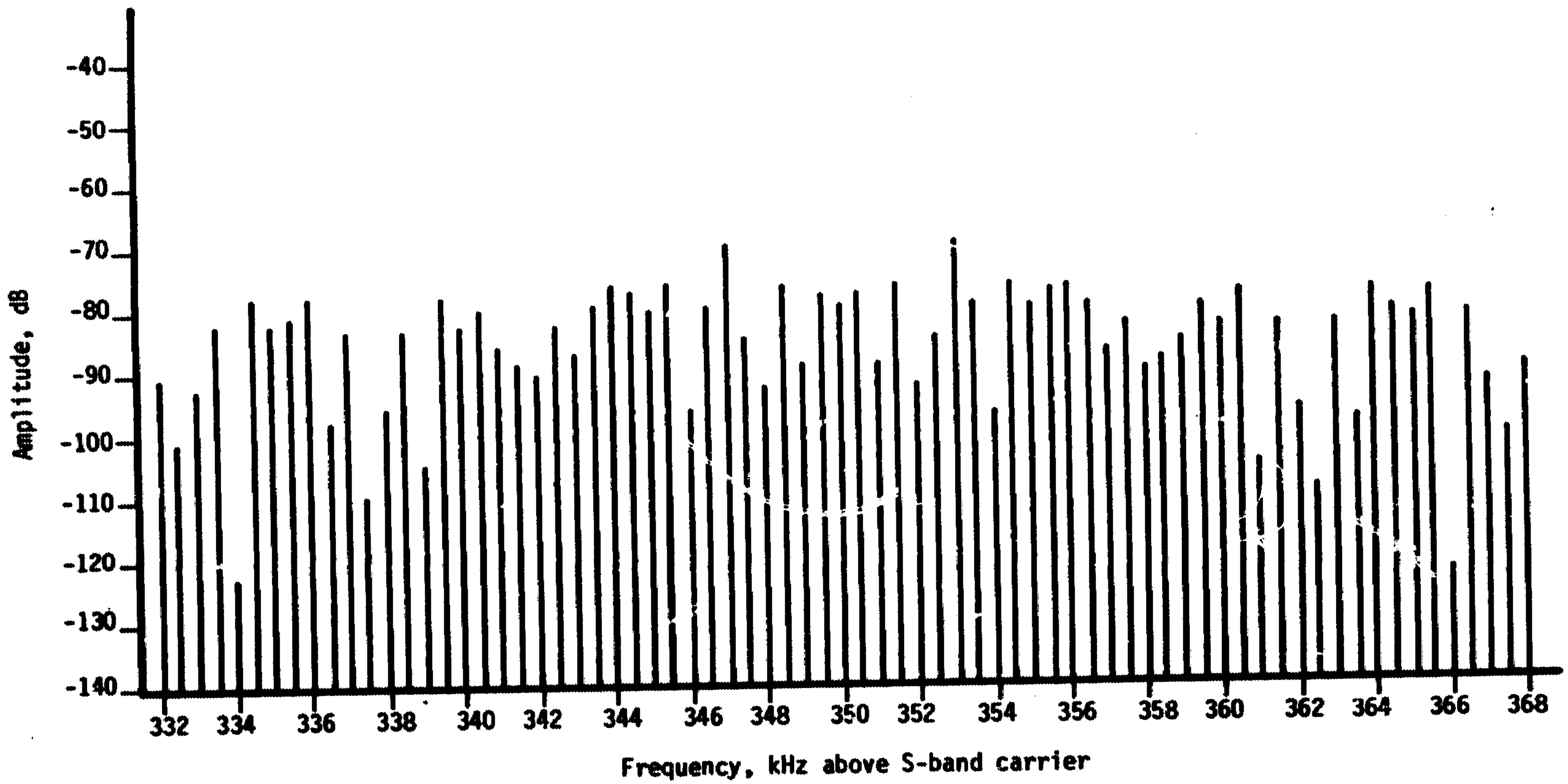


Figure 28. Fifth sideband group of S-band spectrum for command data modulation.

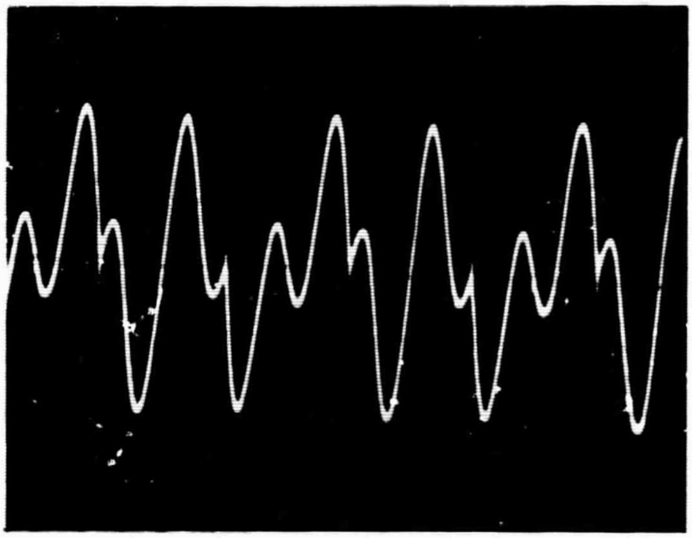
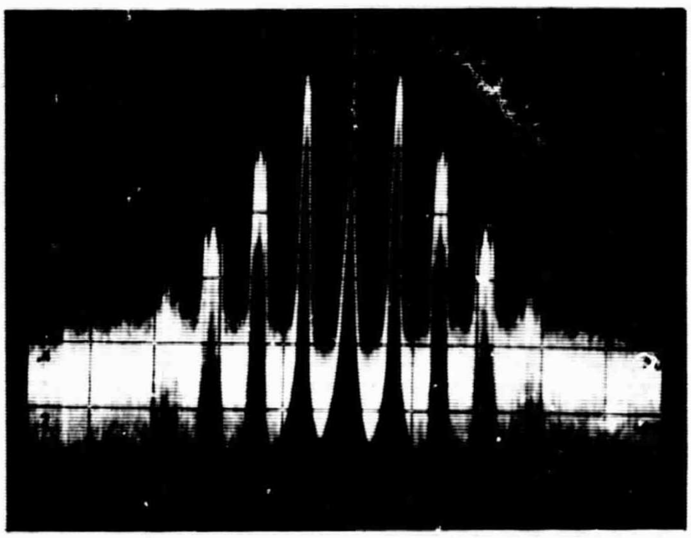


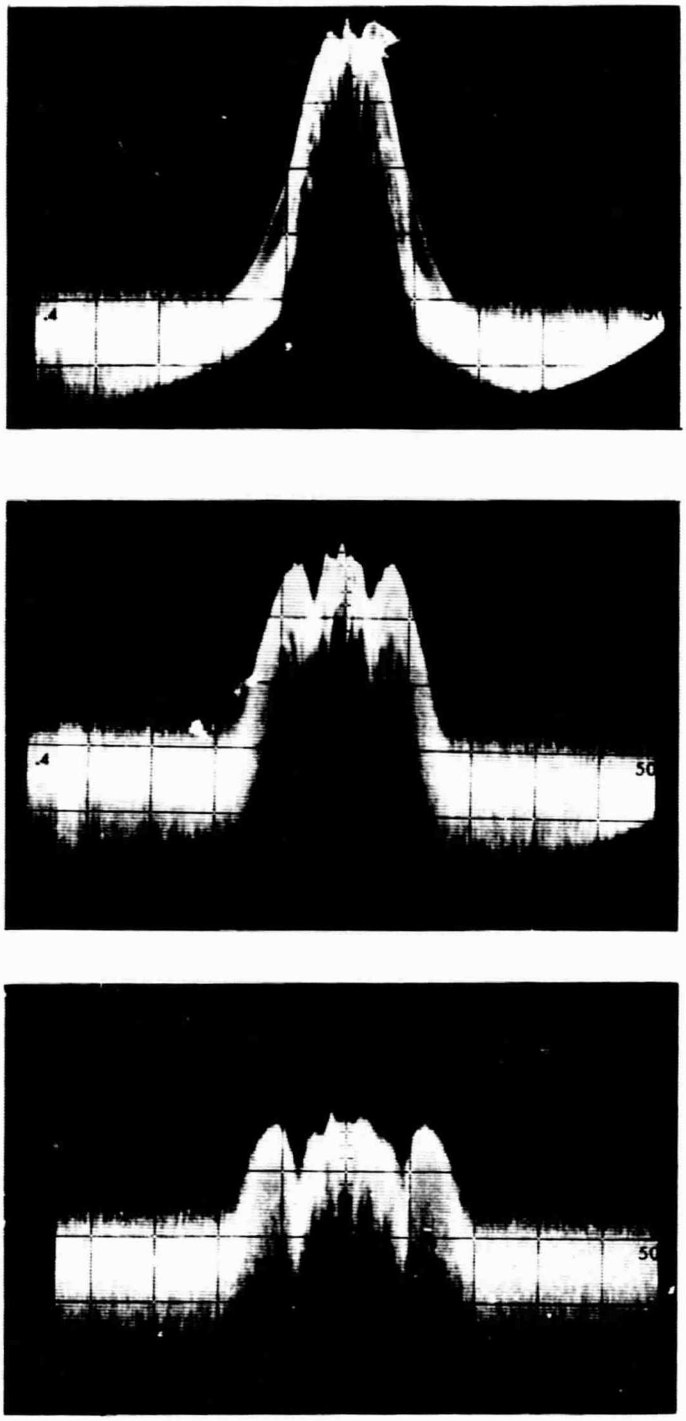
Figure 29. Baseband signal used to frequency modulate the command data subcarrier oscillator.



Vertical: 10 dB/cm

Horizontal: 100 kHz/cm

Figure 30. S-band spectrum for command data modulation of the up-link signal generator.



Vertical: 10 dB/cm

Horizontal: 10 kHz/cm

Figure 31. First three sideband groups below the S-band carrier for command data modulation of the up-link signal generator.

Figure 32. Comparing the shape of these sideband groups with the corresponding group as shown in Figures 24, 25 or 26 indicates good agreement between the calculated and measured values.

C. S-Band Spectrum of the Range Data

1. Derivation of Equations

If the subcarrier oscillator output were removed and only the range data code modulated the S-band transmitter, the signal out of the transmitter would be

$$e_{PM}(t) = \cos[\omega_s t + \beta_2 e_{RD}(t)]$$

$$= \frac{1}{2} e^{j\omega_s t} e^{j\beta_2 e_{RD}(t)} + \frac{1}{2} e^{-j\omega_s t} e^{-j\beta_2 e_{RD}(t)} \quad . \tag{101}$$

In the neighborhood of $\omega = \omega_s$, the spectrum of $e_{PM}(t)$ would be

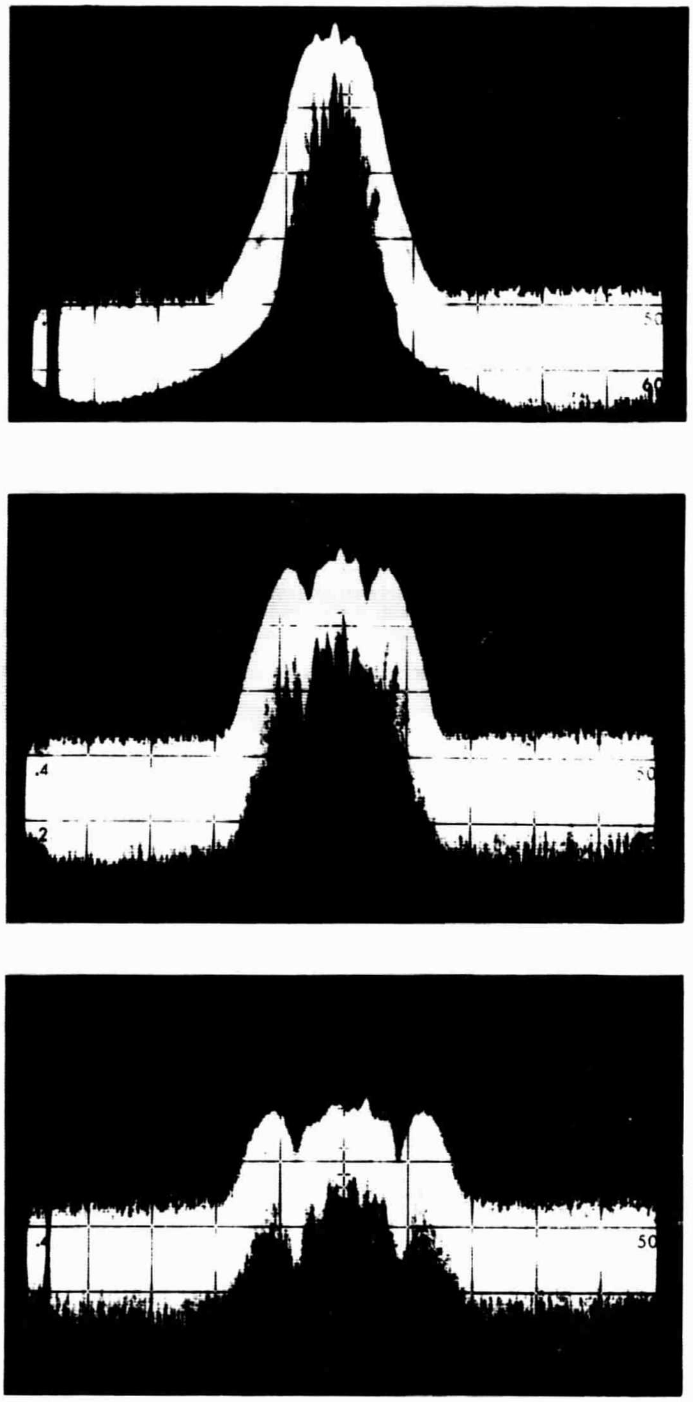
$$E_{PM}(\omega) = \frac{1}{2} \delta(\omega - \omega_s) * \mathcal{F}[e^{j\beta_2 e_{RD}(t)}] \quad . \tag{102}$$

Since the modulation index for the range data signal is less than one ($\beta_2 = 0.6$), the Fourier transform in (102) can be evaluated by expanding the exponential in series and summing the first few terms, thus

$$\mathcal{F}[e^{j\beta_2 e_{RD}(t)}] = \mathcal{F}\left[\sum_{n=0}^{\infty} \frac{j^n \beta_2{}^n}{n!} e^n_{RD}(t)\right] \quad . \tag{103}$$

Let $D(\omega)$ be the baseband spectrum of the range data code. Then

$$D(\omega) = \mathcal{F}[e_{RD}(t)] \quad , \tag{104}$$



Vertical: 10 dB/cm

Horizontal: 10 kHz/cm

Figure 32. First three sideband groups above the S-band carrier for command data modulation of the up-link signal generator.

and the output spectrum at S-band can be written as

$$E_{PM}(\omega) = \delta(\omega - \omega_s) * [1 + j\beta_2 D(\omega) + \frac{j^2\beta_2^2}{2!} D(\omega)*D(\omega) + \frac{j^3\beta_2^3}{3!} D(\omega)*D(\omega)*D(\omega) + \ldots] \quad . \tag{105}$$

Due to the influence of both the factorial and the powers of β_2, the terms in (105) should decrease rapidly. Therefore, this equation provides a tractable method of evaluating the spectrum provided $D(\omega)$ is known.

Determining the baseband spectrum, $D(\omega)$, presents no difficulty. The range data code is a pseudo-noise stream of binary ones and zeros and appears at baseband as a stream of pulses at a fundamental frequency of 498 kHz. The resulting waveform of binary pulses is similar to the wave form for the sub-bit pattern, $X(t)$, given by equation (83). These two differ only in that $X(t)$ was derived specifically for five arbitrary pulses, whereas, the range data code can have varying numbers of pulses. The same method of deriving the spectrum can be applied, however, and produces

$$D(\omega) = \sum_{n=-\infty}^{\infty} \sum_{\mu=1}^{N} \left[I_\mu \cos(2\mu-1)\frac{n\pi}{N} - j\, I_\mu \sin(2\mu-1)\frac{n\pi}{N} \right] \frac{\sin\frac{n\pi}{N}}{n\pi} \delta(\omega - n\omega_{RD}) \quad , \tag{106}$$

where N is the number of pulses in the range data code and $I_\mu = \pm 1$ depending on the polarity of the μth pulse in the code.

2. Computer Program

A computer program was constructed for calculating the output spectrum when only the range data signal was modulating the S-band transmitter. The program calculates the baseband spectrum of the range data by means of Equation (106); the S-band spectrum is then obtained by summing the series given in Equation (105). A copy of the program is given in Appendix C.

The program is constructed so that the length of the range data code can be varied. The particular code is specified by loading a sequence of 1 or -1's in array IMU (see Appendix C), where 1 in the arrays corresponds to binary 1 in the code, and -1 in the array corresponds to binary 0 in the code. The length of the code is given by the third parameter, N, in the call on procedure RANGEDATA which evaluates D(ω). The first two parameters in the procedure call specifies the lower and upper frequency limits (in kHz) at which D(ω) is to be truncated.

Although the value of N may be arbitrarily selected, provision was made in the present program for storage of only 1000 lines in the baseband spectrum. In order to limit the calculation to less than 1000 lines and still give a reasonable representation of the spectrum, the maximum value of N for which computation is practical with this program is in the vicinity of N= 100.

The program was constructed so that as each term in the series given by Equation (105) was computed, the sum through that term could be printed out. Terms up to fourth order were computed; examination of the outputs indicated that the sum through the fourth order term did not differ significantly from the sum through the third order term. Consequently, the summation through fourth order as produced by the program should be a good representation of the spectrum.

3. Results of Computations

Using the program described above, the output spectrum when the range data alone was modulating the S-band transmitter was computed for various range data codes. For the first of these calculations, alternating bit patterns were used for the range code rather than pseudonoise sequences. Several such codes of different length were used, and in each case the number of bits was odd so that the modulating wave form was not strictly a square wave. The pattern used for a seven bit code, for example, is shown in Figure 33.

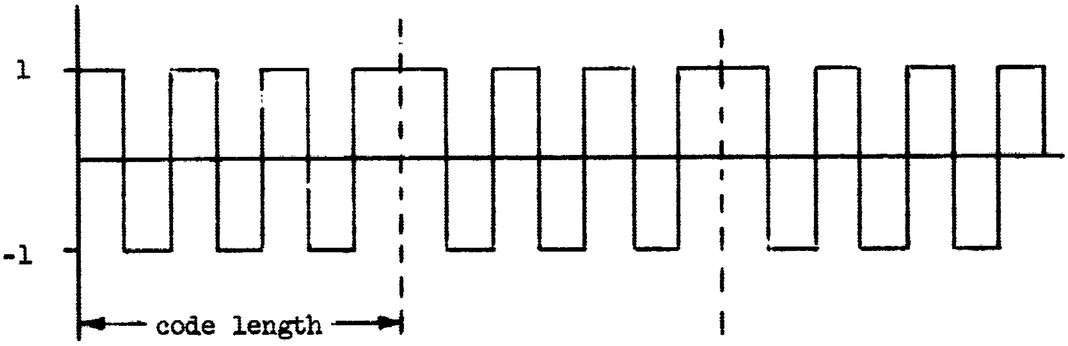


Figure 33. Time waveform of range data code for seven alternating bits.

The computed spectrum for a 13 bit alternating code and a modulation index (β_2) of 0.6 is shown in Figure 34. To check the validity of the calculations, a pulse generator to simulate the range code patterns was constructed and used to modulate an S-band transmitter so that measured spectra could be obtained for comparison. Using the same 13 bit alternating code and a modulation index of 0.6, the spectrum shown in Figure 35 was obtained.

As a further check on the analysis, both the computations and measurements were repeated with the modulation index reduced to 0.3. The computed spectrum is shown in Figure 36 and the measured spectrum in Figure 37.

Similar spectra were computed and measured for alternating bit codes of other lengths. Figure 38 shows the spectrum for a 7 bit code, and Figure 39 shows the spectrum for a 29 bit code. In both cases the modulation index was 0.6. Note that the envelope of the side bands is similar for all of the alternating bit codes.

The output spectrum was also computed for several pseudo-noise sequences of range data bits. The computed spectra for pseudo-noise codes of length 3, 7, 15, and 31 bits are shown in Figures 40 - 43. Note that the spectral envelope of the sidebands is similar for each of these spectra. It can be shown theoretically that the envelope of the sidebands will be similar for any pseudo-noise sequence[3].

D. Total S-Band Spectrum

1. Derivation of Equations

When both the command data and the range data are used to modulate the S-band transmitter, the output signal has the form

$$e_{PM}(t) = \cos[\omega_s t + \beta_1 e_{FM}(t) + \beta_2 e_{RD}(t)]$$

$$= \frac{1}{2} e^{j\omega_s t} e^{j\beta_1 e_{FM}(t)} e^{j\beta_2 e_{RD}(t)}$$

$$+ \frac{1}{2} e^{-j\omega_s t} e^{-j\beta_1 e_{FM}(t)} e^{-j\beta_2 e_{RD}(t)} \quad . \qquad (107)$$

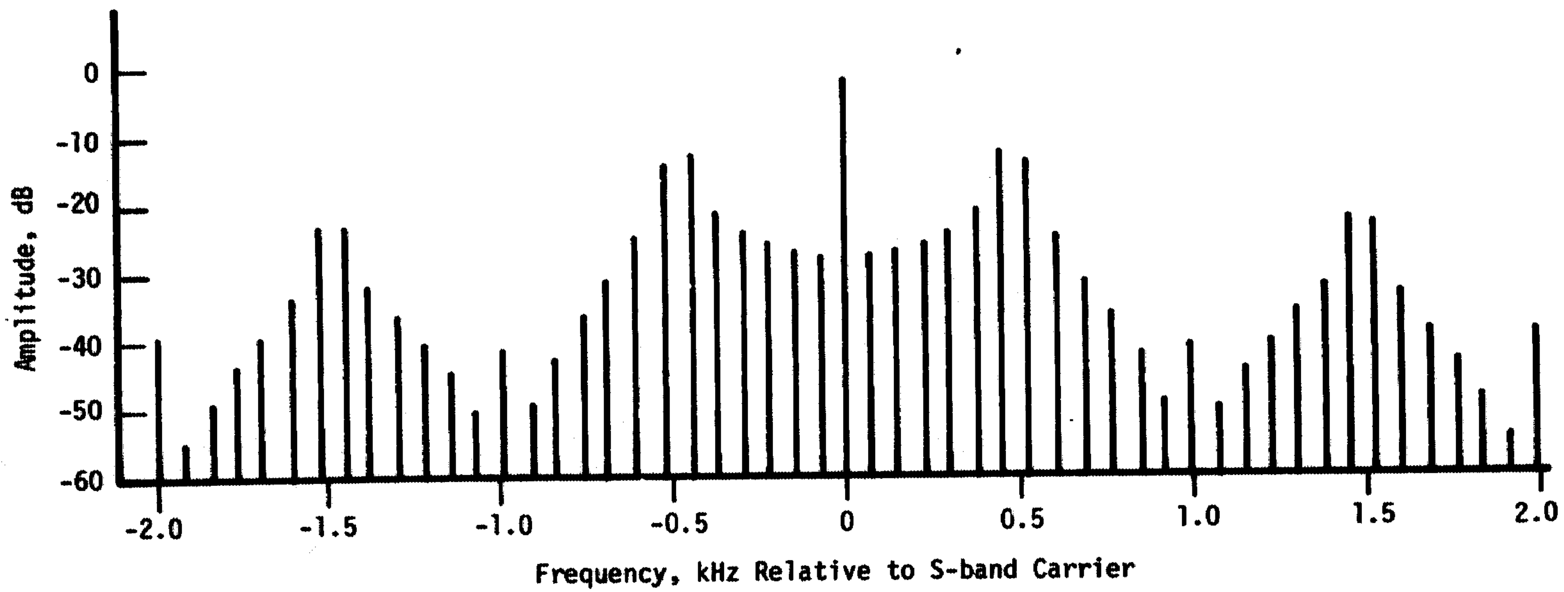
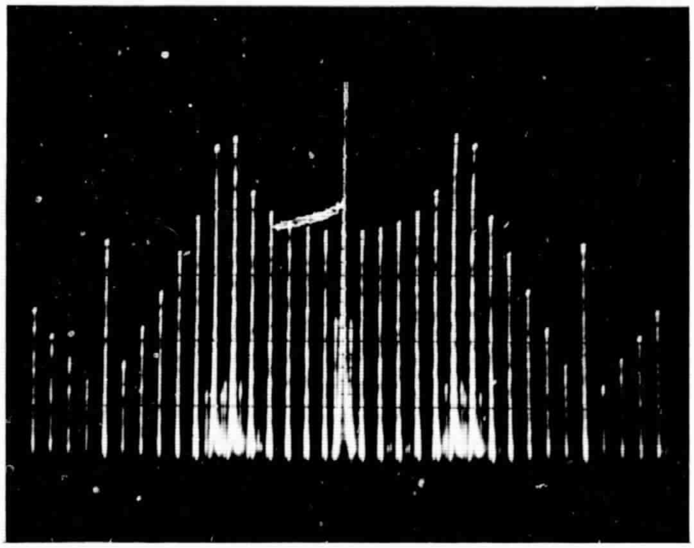
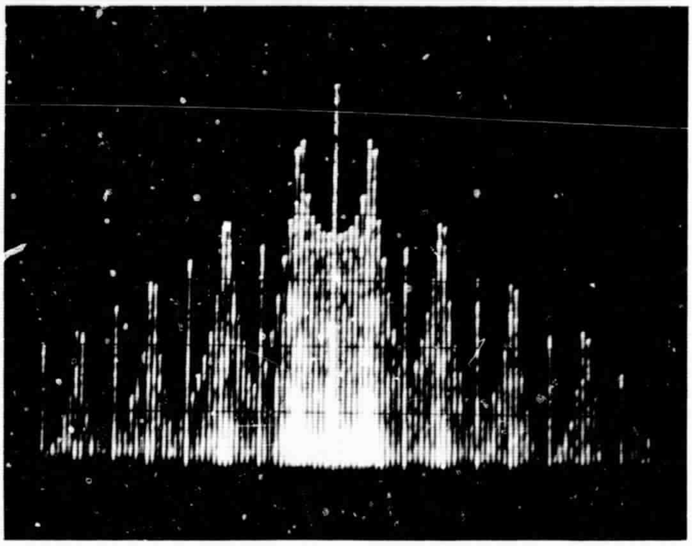


Figure 34. Computed S-band spectrum for a modulating signal consisting of 13 alternating bits applied to the range code input of the phase modulator, $\beta_2 = 0.6$.



(a) Horizontal: 300 kHz/cm
Vertical: 10 dB/cm



(b) Horizontal: 1 MHz/cm
Vertical: 10 dB/cm

Figure 35. Measured S-band spectrum for a modulating signal consisting of 13 alternating bits applied to the range code input of the phase modulator, $\beta_2 = 0.6$.

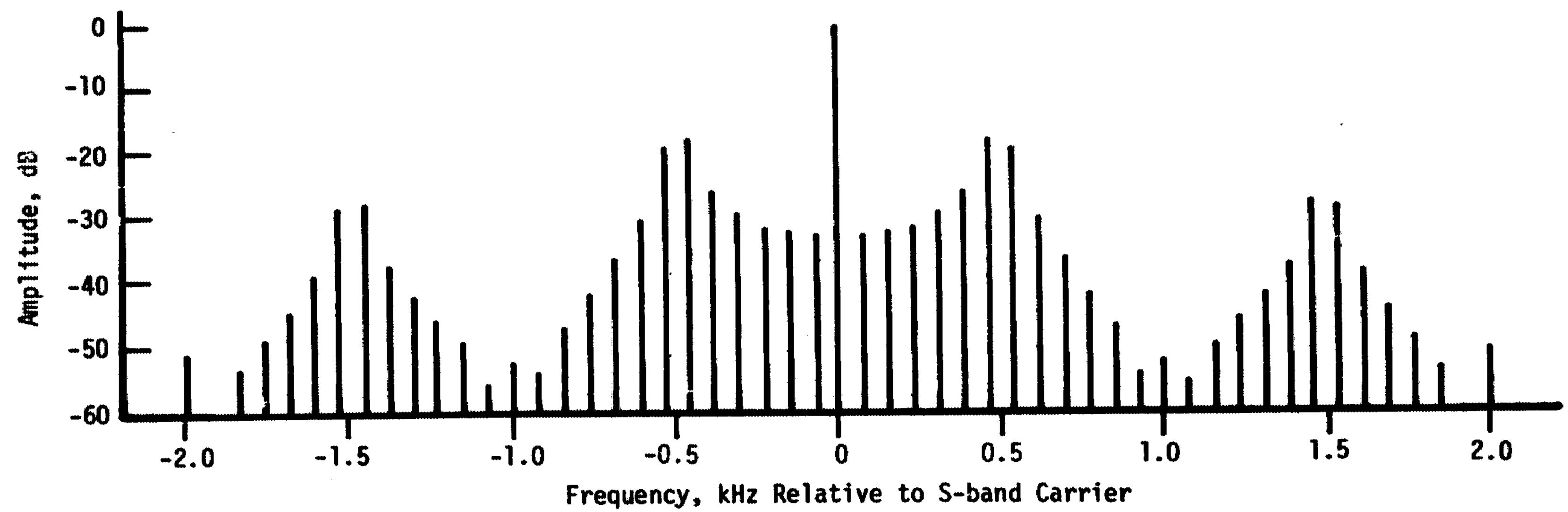
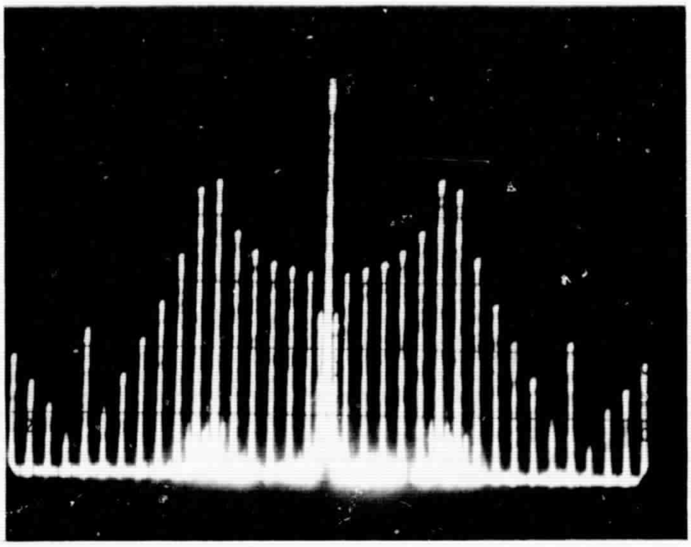
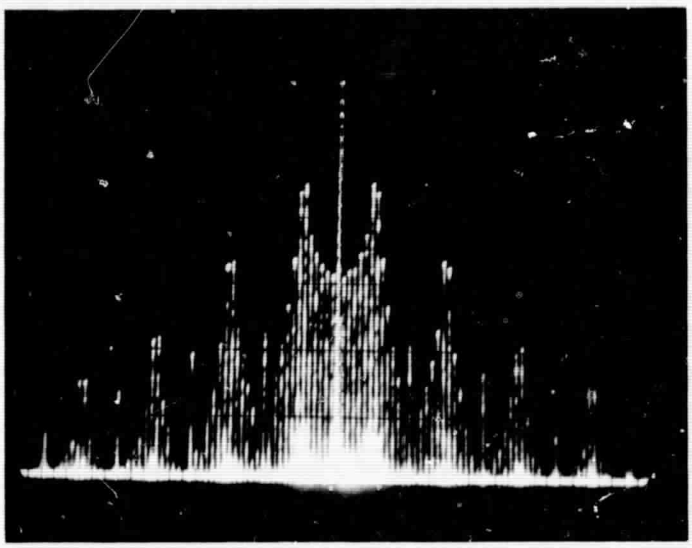


Figure 36. Computed S-band spectrum for a modulating signal consisting of 13 alternating bits applied to the range code input of the phase modulator, $\beta_2 = 0.3$.

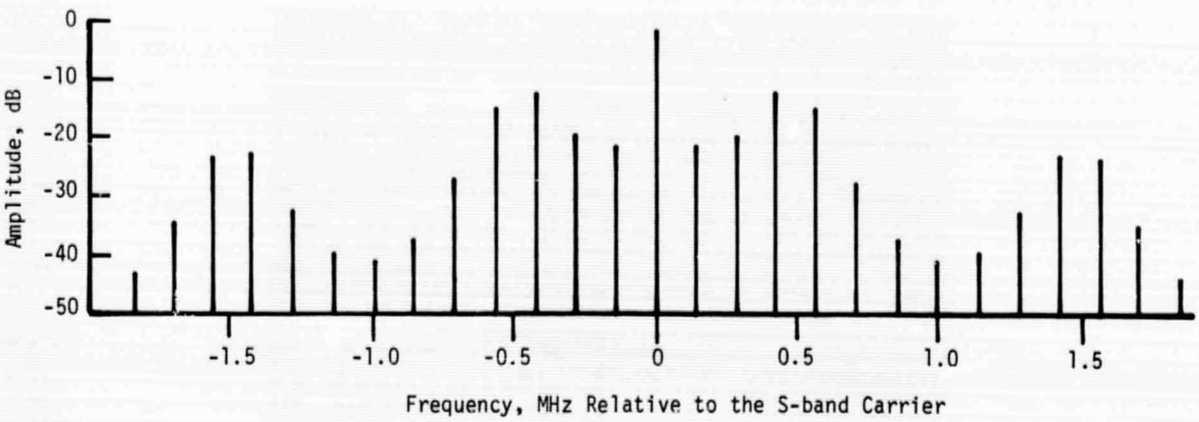


(a) Horizontal: 300 kHz/cm
Vertical: 10 dB/cm

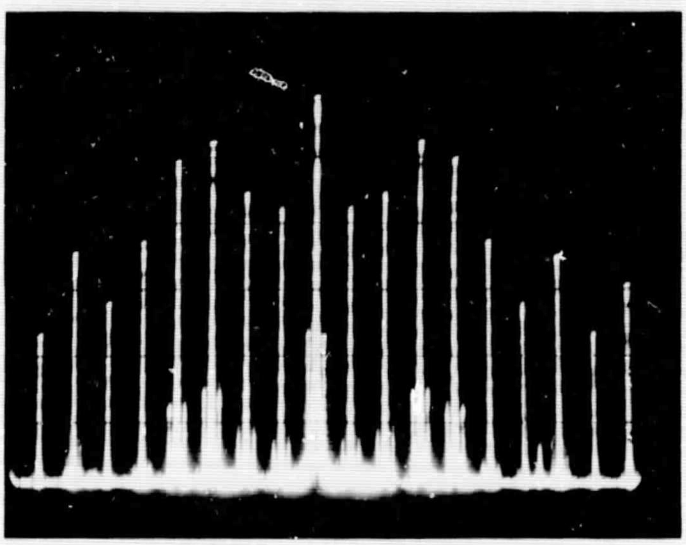


(b) Horizontal: 1 MHz/cm
Vertical: 10 dB/cm

Figure 37. Measured S-band spectrum for a modulating signal consisting of 13 alternating bits applied to the range code input of the phase modulator, $\beta_2 = 0.3$.

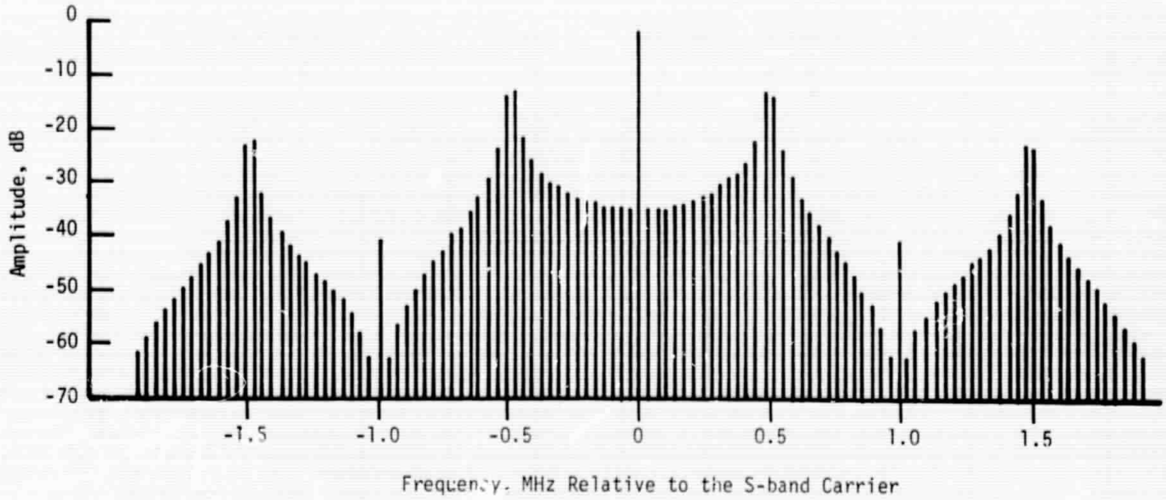


(a) Computed

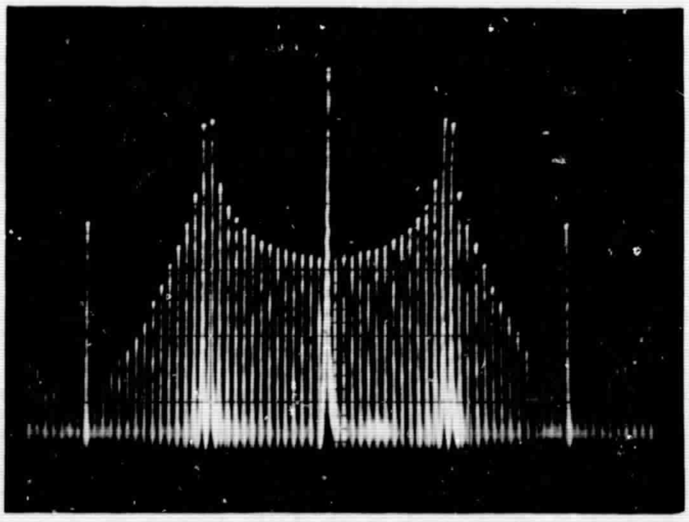


(b) Measured:
Horizontal: 300 kHz/cm
Vertical: 10 dB/cm

Figure 38. Computed and measured S-band spectra for a modulating signal consisting of 7 alternating bits applied to the range code input of the phase modulator, $\beta_2 = 0.6$.



(a) Computed



(b) Measured:
Horizontal: 300 kHz/cm
Vertical: 10 dB/cm

Figure 39. Computed and measured S-band spectra for a modulating signal consisting of 29 alternating bits applied to the range code input of the phase modulator, $\beta_2 = 0.6$.

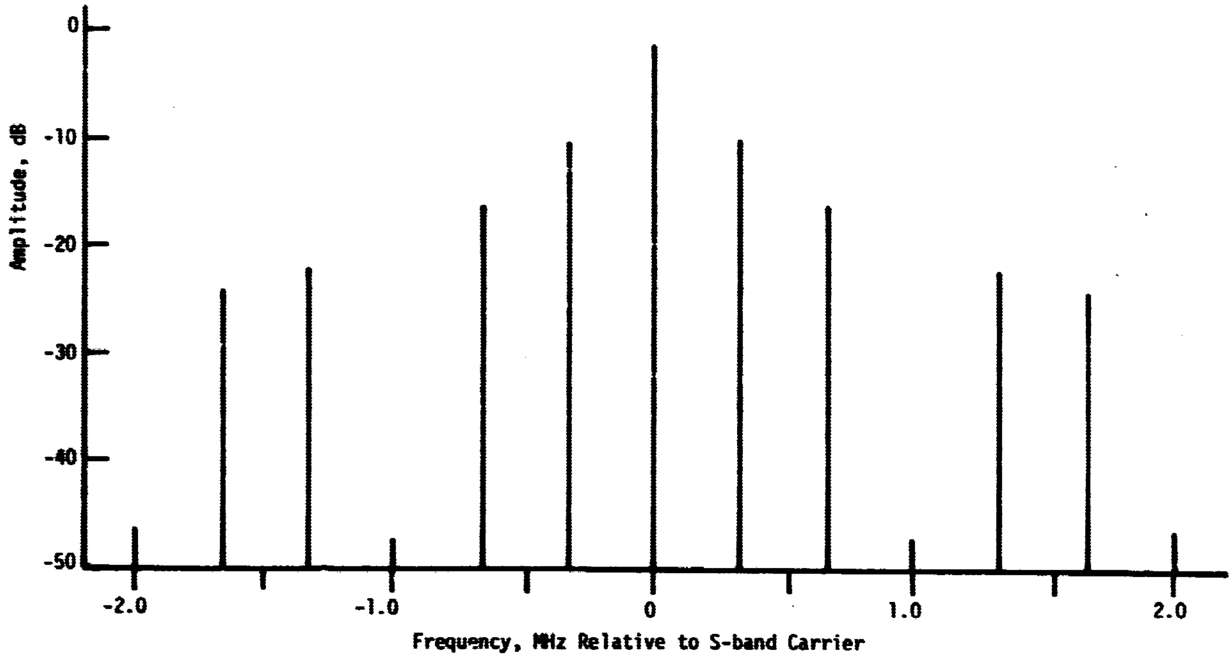


Figure 40. Computed S-band spectrum for a modulating signal consisting of a 3 bit pseudo noise code applied to the range code input to the phase modulator, $\beta_2 = 0.6$.

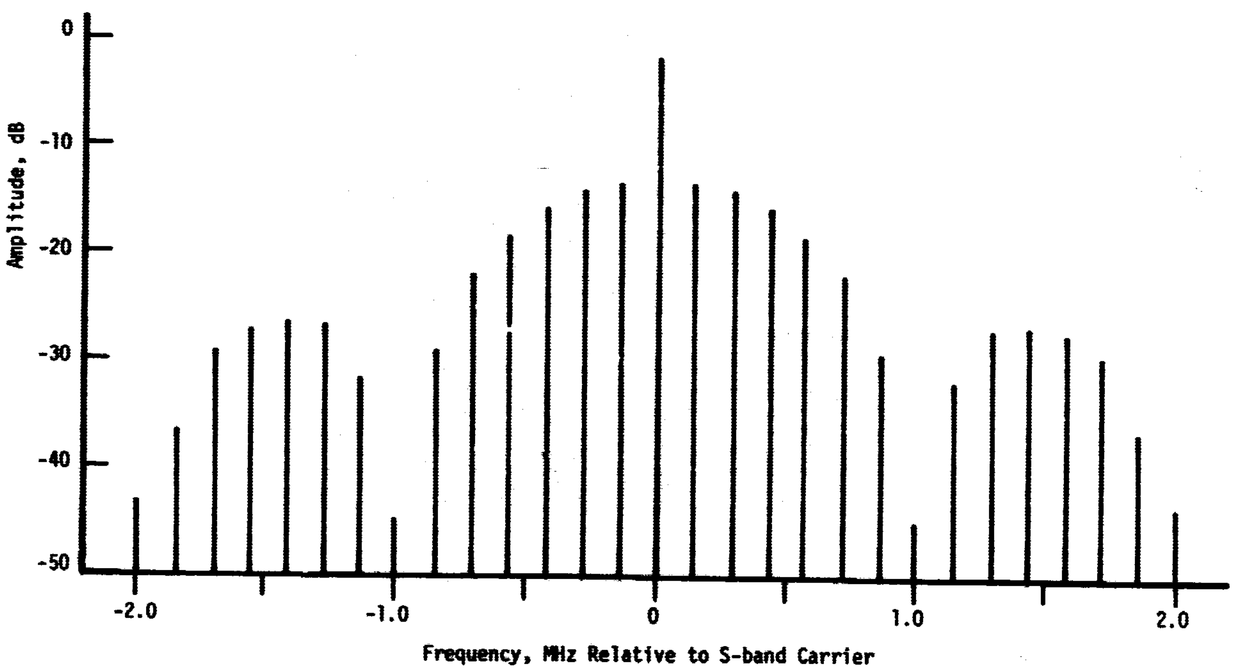


Figure 41. Computed S-band spectrum for a modulating signal consisting of a 7 bit pseudo noise code applied to the range code input to the phase modulator, $\beta_2 = 0.6$.

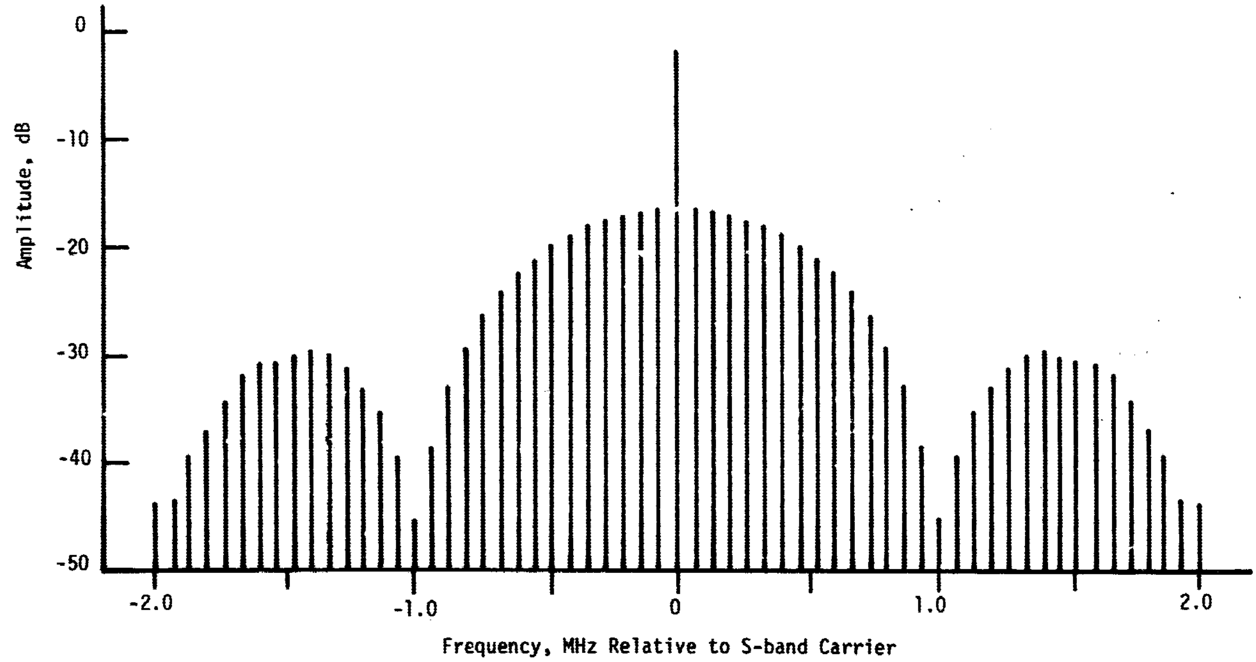


Figure 42. Computed S-band spectrum for a modulating signal consisting of a 15 bit pseudo noise code applied to the range code input of the phase modulator, $\beta_2 = 0.6$.

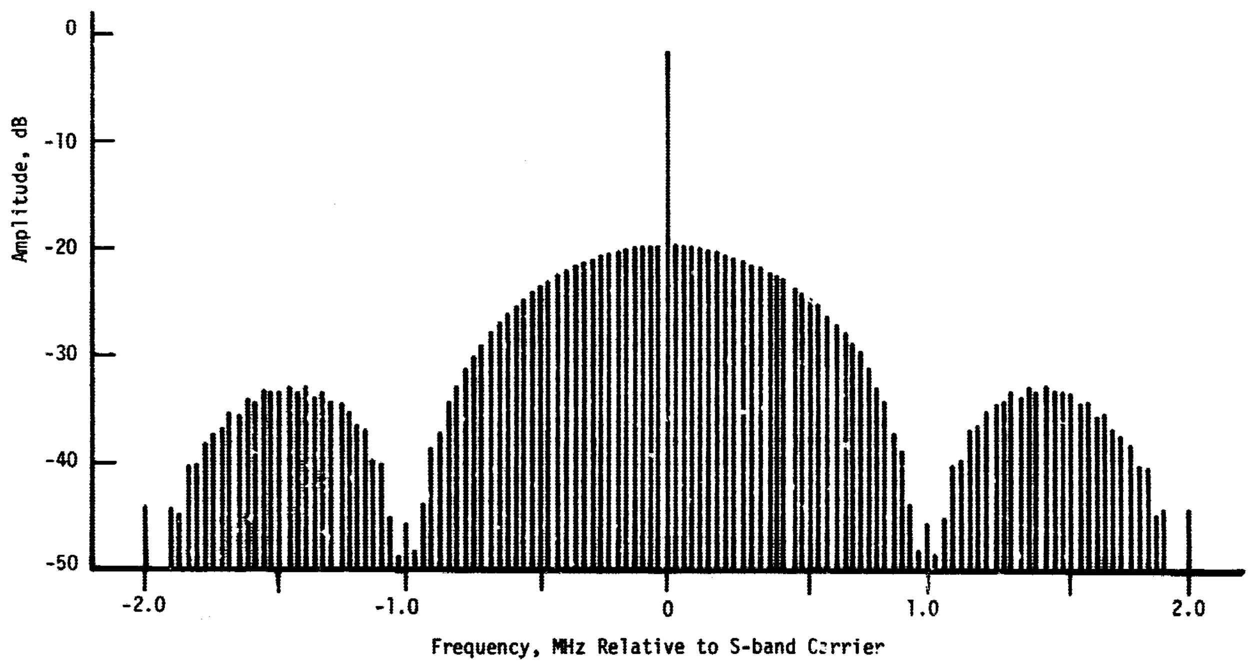


Figure 43. Computed S-band spectrum for a modulating signal consisting of a 31 bit pseudo noise code applied to the range code input of the phase modulator, $\beta_2 = 0.6$.

In the neighborhood of $\omega = \omega_s$, the spectrum of $e_{PM}(t)$ is

$$E_{PM}(\omega) = \frac{1}{2}\,\delta(\omega - \omega_s) * \mathcal{F}[e^{j\beta_1 e_{FM}(t)}] * \mathcal{F}[e^{j\beta_2 e_{RD}(t)}] \quad . \tag{108}$$

Now $\mathcal{F}[e^{j\beta_1 e_{FM}(t)}] = H(\omega)$ and is given in Equation (100); and $\mathcal{F}[e^{j\beta_2 e_{RD}(t)}]$ can be approximated by the series given in Equation (105). While it is theoretically possible to compute the entire S-band spectrum by means of these equations, there is a practical difficulty in doing so. The narrow spacing of the lines in the command data spectrum would produce thousands of lines per Megahertz in the output spectrum. In addition, due to the wide spread of the range data spectrum, the output S-band spectrum will be many MHz wide. Thus the total spectrum will contain an enormous number of lines.

An alternative procedure was used to calculate an S-band spectrum which, though not complete, permits the form of the entire spectrum to be deduced. This procedure was merely to remove the command data modulation from the subcarrier oscillator and to use only the unmodulated subcarrier oscillator itself as the signal from the command channel. With this change, the narrow line spacing is avoided and the number of lines in the spectrum is small enough so that its computation is feasible. This procedure produces a spectrum whose envelope should be similar to that of the actual spectrum. Furthermore, the actual spectrum will differ only in that it would have FM sidebands (similar to those in Figure 24) about each line.

To calculate the reduced spectrum, it is necessary only to replace $e_{FM}(t)$ with $\cos \omega_c t$, where ω_c is the subcarrier frequency. Let

$$\begin{aligned} S_1(t) &= e^{j\beta_1 \cos \omega_c t} \\ &= e^{j\beta_1 \sin(\omega_c t + \frac{\pi}{2})} \\ &= \sum_{n=-\infty}^{\infty} J_n(\beta_1)\, e^{jn\omega_c t}\, e^{jn\frac{\pi}{2}} \quad . \end{aligned} \tag{109}$$

The transform of $S_1(t)$ will be

$$S_1(\omega) = \sum_{n=-\infty}^{\infty} J_n(\beta_1)\, e^{jn\frac{\pi}{2}}\, \delta(\omega - n\omega_c)$$

$$= \sum_{n=-\infty}^{\infty} J_n(\beta_1)\, [\cos n\tfrac{\pi}{2} + j \sin n\tfrac{\pi}{2}]\, \delta(\omega - n\omega_c) \quad . \tag{110}$$

2. Computer Program

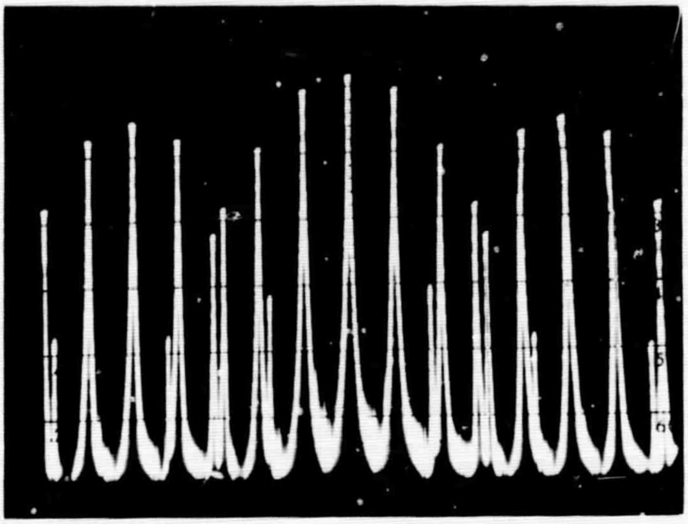
Constructing the computer program for this calculation was relatively simple, since it is almost identical to the program that was used to compute the spectrum when only the range data were present. It was only necessary to add the calculation of $S_1(\omega)$ as given in Equation 110, and then to call up the convolution procedure to convolve $S_1(\omega)$ with the range data spectrum. The complete program is listed in Appendix D.

3. Results of Computations

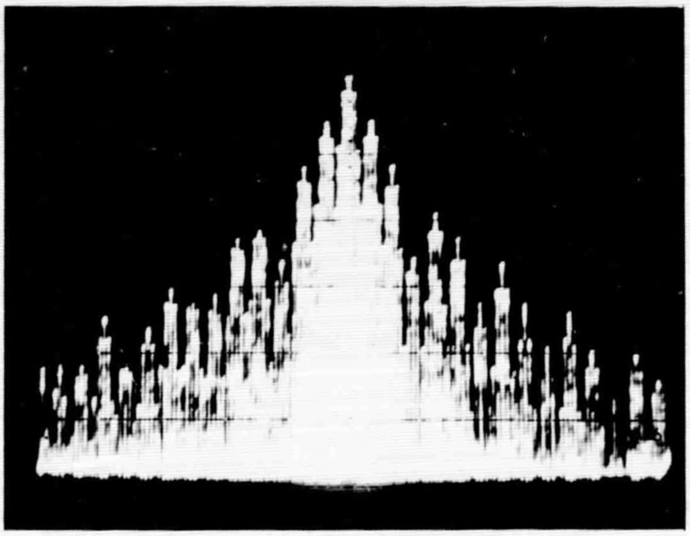
The output spectrum of the S-band transmitter when modulated with both the subcarrier and the range data was computed for several different pseudo-noise codes. For verification of the calculations, measured spectra were obtained in the laboratory from the S-band transmitter when similar modulations were applied. Even with the modulation removed from the subcarrier, the output spectrum contained so many lines that detailed comparison of measured and computed values could easily be made only for very short range data codes.

For the first trial, the three bit code +1, -1, +1 was used. The measured spectrum is shown in Figure 44 and the computed spectrum is shown in Figure 45. A comparison of the measured and computed values for a number of lines in the center of the spectrum is shown in Figure 46. The measured values were read from the photograph in Figure 44(a) and were normalized by making the carrier levels equal.

Similar calculations have been made for PN codes of 7, 15, and 31 bits. Due to the large number of lines that appear in these spectra, presentation in graphical form did not appear practical. A copy of the computer output for the 15 bit code is included in Appendix D.



(a) Horizontal: 100 kHz/cm
Vertical: 10 dB/cm



(b) Horizontal: 1 MHz/cm
Vertical: 10 dB/cm

Figure 44. Measured S-band spectra for a modulating signal consisting of a 3 bit pseudo noise code and unmodulated 70 kHz command data subcarrier applied to the input of the phase modulator, $\beta_1 = 1.22$, $\beta_2 = 0.6$.

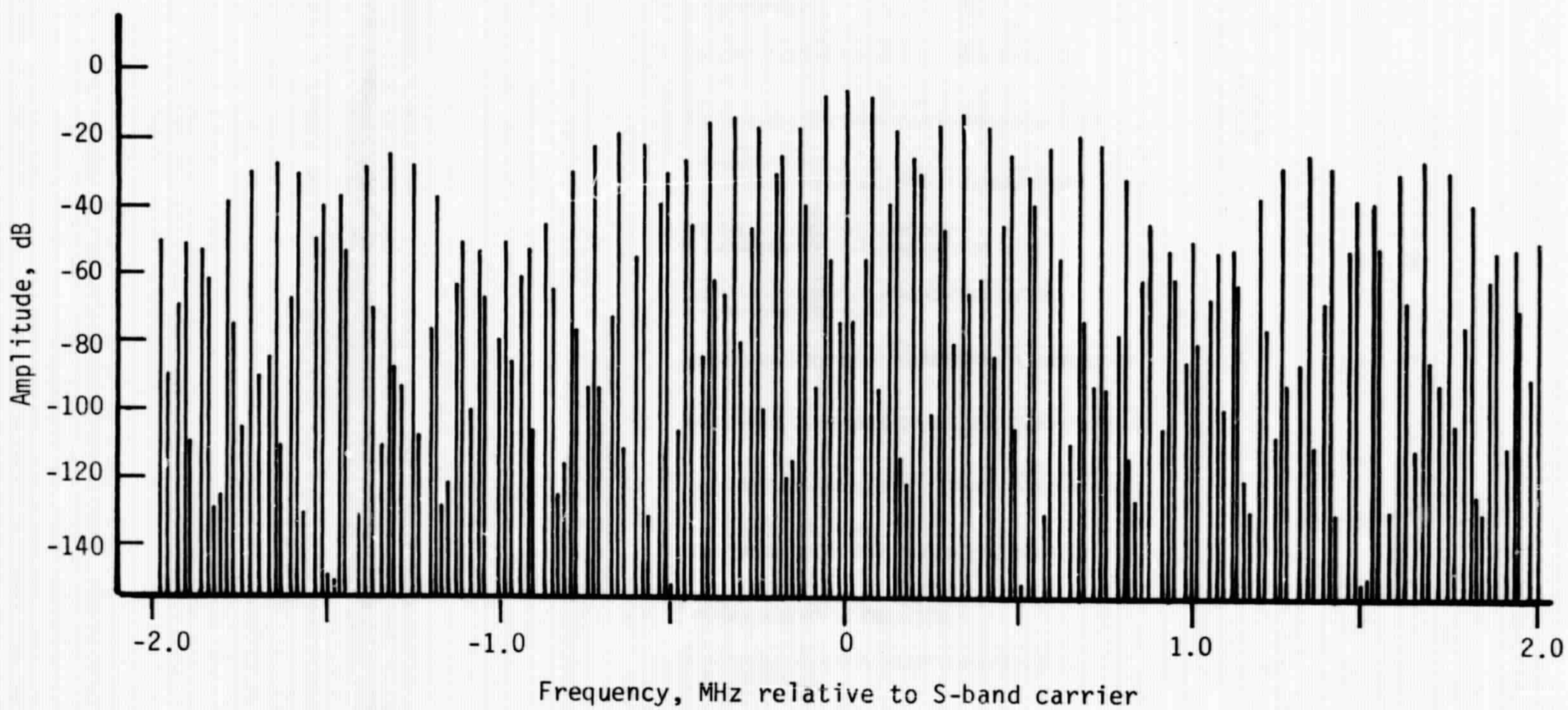


Figure 45. Computed S-band spectrum for a modulating signal consisting of a 3 bit pseudo noise code and the unmodulated 70 kHz command data subcarrier applied to the input of the phase modulator, $\beta_1 = 1.22$, $\beta_2 = 0.6$.

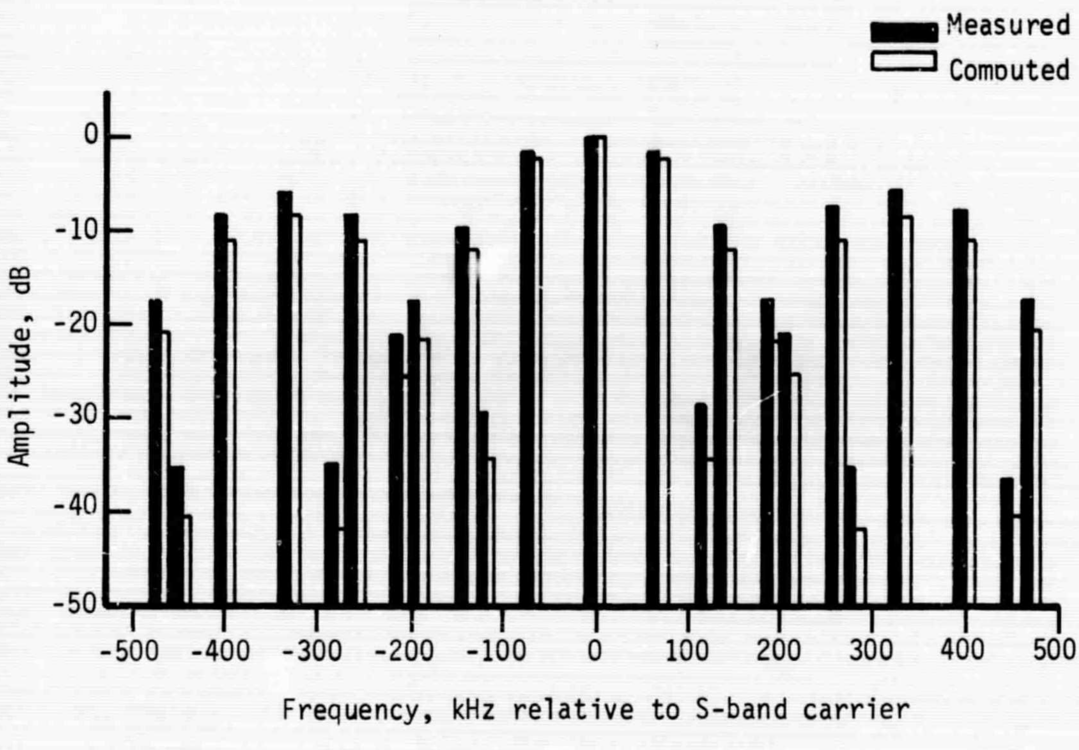


Figure 46. Comparison of the computed and measured spectral components of the S-band spectrum for a modulating signal consisting of a 3 bit pseudo noise code and the unmodulated 70 kHz command data subcarrier applied to the input of the phase modulator, $\beta_1 = 1.22$, $\beta_2 = 0.6$.

VII. CONCLUSIONS

Methods have been developed for the calculation of the frequency spectra of (1) the baseband command data signal (2) the baseband range code signal (3) the frequency modulated output of the command subcarrier generator, and (4) the output of the S-band up link signal generator. The S-band spectrum was obtained for modulating signals applied to the S-band phase modulator which consisted of (1) the modulated command data subcarrier (2) the range code signal, and (3) both the range code and the unmodulated command data subcarrier. Good agreement has been obtained between the calculated and measured values. The computer programs developed to implement the calculation from the mathematical derivations can be used to study the effect of variation in system parameters, such as modulation indices, on the spectra obtained for the various systems.

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VIII. BIBLIOGRAPHY

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2. Gullemin, E. A., The Mathematics of Circuit Analysis, John Wiley & Sons, Inc., New York, 1958, pp. 506-509.

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APPENDICES

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A. Computer program listing and sample calculation for the FM spectrum of the subcarrier oscillator.

Listing of the ALGOL program for computing the output spectrum of the frequency modulated subcarrier oscillator, followed by a sample of the output. This sample was calculated for a peak frequency deviation of 5 kHz and an alternating sub-bit pattern.

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```
% CALCULATION OF FM SPECTRUM AT OUTPUT OF SUBCARRIER OSCILLATOR.
BEGIN
        LABEL EXIT;
        INTEGER J,K,N1,N2,NM,NY,I1,I2,I3,I4,I5,TM ;
        REAL COEF,ARG,LAM,PI,F1,HAFPI;
        REAL ARRAY     S2,S3[0:2,0:21],M[0:2,0:160],X[0:2,0:220],
                          S1[0:2,0:35] ;
        FILE OUT PRT 6(2,15);
        FORMAT FMT1("LINE",X3,"FREQUENCY,",X6,"COMPLEX COEFFICIENTS",
            X12,"AMPLITUDE",X7,"DECIBELS",X5,"CUMMULATIVE"/X1,"NO.",
                X4,"KILOHERTZ",X7,"REAL",X11,"IMAGINARY",X7,
                "COEFFICIENT",X5,"REL TO MAX",X7,"POWER"//
                 9( 5(I4,X2,F9.3,3(X2,E15.6),X5,F7.2,X5,E15.6/)/)////);
% ***********************************************************************
   PROCEDURE PRINTIME; BEGIN FORMAT FMTT(/"PROCESSOR TIME",F9.3,X10,      PT1
     "IO TIME",F9.3/); LIST LSTT(TIME(2)/60.0,TIME(3)/60.0);              PT2
     WRITE(PRT, FMTT,LSTT); END PRINTIME;                                 PT3
% ***********************************************************************
        REAL    PROCEDURE FACTORIAL(N);                                   F 1
        VALUE N; INTEGER N ; BEGIN INTEGER I;
        REAL F ;  F ← 1.0 ;                                               F 2 1
        FOR I ← 2 STEP 1 UNTIL N DO F ← I × F; FACTORIAL ← F END ;        F 3
%   *********************************************************************
        REAL PROCEDURE JAY(N,X);                                          J 1
        VALUE N,X ; INTEGER N ; REAL X ; BEGIN INTEGER   P,NPOS; REAL     J 2
        XSQ,    A,SUMA,F; LABEL RPT; NPOS←ABS(N); A←SUMA←P←1; XSQ←X×X;    J 3
   RPT: A ← - (XSQ × A)/(4.0 × P × (NPOS +P)); SUMA ← SUMA + A; P←P+1;    J 4
        IF ABS(A) > 1.0@-7 THEN GO TO RPT;                                J 5
        F ← (((SIGN(N)×X/2.0)*NPOS)×SUMA)/FACTORIAL(NPOS); JAY←F  END;    J 6
%   *********************************************************************
```

```
            PROCEDURE PRINT(A);    ARRAY A[0,0];
REGIN       INTEGER I,K ;
            REAL SUMP,X,Y  ;
            ARRAY POWER[-1:999];
            FORMAT FMTM("LINE",X9,"FREQ",X14,"REAL",X13,"IMAG",X10,
                    "AMPLITUDE",X7,"SUM OF POWER"/
                      10(5(I4,5(X2,F15.8)/)/) );
            LIST LSTM(FOR I ← 0 STEP 1 UNTIL K DO
                     [I,A[0,I],A[1,I],A[2,I],
                     SQRT(POWER[I] - POWER[I-1]),
                                            POWER[I] ] ) ;
            K ← A[1,0] ;
            SUMP ← 0.0 ;
            POWER[-1] ← POWER[0] ← 0;
            FOR I ← 1 STEP 1 UNTIL K DO
REGIN       X ← A[1,I] ;  Y ← A[2,I] ;
            SUMP     ← SUMP + X×X + Y×Y ;
            POWER[I] ← SUMP                                       END;
            WRITE (PRT,FMTM,LSTM);
            WRITE (PRT[PAGE]);
END PRINT;
%    ***********************************************************************
            PROCEDURE CONVOLVE(A,B,C,F);                                       C 1
            VALUE F; REAL F;               ARRAY A,B,C[0,0];                   C 1 1
REGIN       INTEGER I,J,K,L,ASTOP,BSTOP,CMAX,CSTOP,ILO,IHI,JLO,JHI;            C 2
            REAL FRQ,RF,IM,FA,RA,TA,RB,IB,FFF;                                 C 2 1
            BOOLEAN SKIP1;                                                     C 2 2
            LABEL L1;                                                          C 2 3
            CSTOP ← C[0,0] - 1.0 ;                                             C 2 2
            FOR I ← 1 STEP 1 UNTIL CSTOP + 1 DO                                C 3
            C[0,I] ← 99999999.0;                                               C 4
```

```
        CMAX ← 0; ASTOP ← A[1,0]; BSTOP ← B[1,0];                        C 5
        EFF ← -B[0,BSTOP] - F - 1@-6; ILO ← 1;                           C 5 1
        WHILE A[0,ILO] < EFF DO ILO ← ILO+1;                             C 5 2
        EFF ← -B[0,1] + F + 1@-6; IHI ← ASTOP;                           C 5 3
        WHILE A[0,IHI] > EFF DO IHI ← IHI - 1; SKIP1 ← FALSE;            C 5 4
        FOR I ← ILO STEP 1 UNTIL IHI DO                                  C 6
BEGIN   FA ← A[0,I] ; RA ← A[1,I] ; IA ← A[2,I] ; K ← 1 ;                C 6 1
        IF SKIP1 THEN GO TO L1;                                          C 6 2
        EFF ← -F - FA - 1@-6; JLO ← 1;                                   C 6 3
        WHILE B[0,JLO] < EFF DO JLO ← JLO + 1;                           C 6 4
        IF JLO = 1 THEN SKIP1 ← TRUE;                                    C 6 5
L1:     EFF ← F - FA + 1@-6; JHI ← BSTOP;                                C 7
        WHILE B[0,JHI] > EFF DO JHI ← JHI - 1;                           C 7 1
        FOR J ← JLO STEP 1 UNTIL JHI DO                                  C 7 2
BEGIN   RB ← B[1,J] ; IB ← B[2,J] ;                                      C 8
        FRQ ← FA + B[0,J] ;                                              C 8 1
        RE ← RA × RB - IA × IB ;                                         C 9
        IM ← RA × IB + IA × RB ;                                         C10
        WHILE FRQ > C[0,K] + 1.0@-6 DO K ← K + 1 ;                       C11
        IF ABS(FRQ - C[0,K]) < 1.0@-6 THEN                               C12
BEGIN   C[1,K] ← C[1,K] + RE;  C[2,K] ← C[2,K] + IM;               END   C13
ELSE BEGIN FOR L ← CMAX STEP -1 UNTIL K DO                               C14
BEGIN   C[0,L+1] ← C[0,L];  C[1,L+1] ← C[1,L];  C[2,L+1] ← C[2,L] END;   C15
        CMAX ← CMAX + 1; C[0,K] ← FRQ; C[1,K] ← RE; C[2,K] ← IM;         C16
        IF CMAX > CSTOP        THEN
BEGIN   C[1,0] ← CMAX ;
        PRINT(C); GO TO EXIT  END ;
END; END; END;                                                           C17
        C[1,0] ← CMAX ;
END CONVOLVE;
%   *********************************************************************
```

```
        PROCEDURE SUM(A,B);    ARRAY A,B[0,0];
BEGIN   INTEGER I,K,L,ASTOP,BMAX;
        ASTOP ← A[1,0]; BMAX ← B[1,0]; K ← B[0,0];
        FOR I ← BMAX +1 STEP 1 UNTIL K DO
BEGIN   B[0,I] ← 999999999.0; B[1,I] ← B[2,I] ← 0.0 ;          END;
        K ← 1 ; FOR I ← 1 STEP 1 UNTIL ASTOP DO
BEGIN   WHILE A[0,I] > B[0,K] DO K ← K + 1; IF A[0,I] = B[0,K] THEN
BEGIN   B[1,K] ← B[1,K] + A[1,I]; B[2,K] ← B[2,K] + A[2,I]     END
ELSE BEGIN FOR L ← BMAX STEP -1 UNTIL K DO
BEGIN   B[0,L+1] ← B[0,L]; B[1,L+1] ← B[1,L]; B[2,L+1] ← B[2,L] END;
        BMAX ← BMAX+1; B[0,K] ← A[0,I]; B[1,K]←A[1,I]; B[2,K]←A[2,I];
END; END; B[1,0] ← BMAX ;
END SUM;
%   ****************************************************************
        WRITE (PRT[NO]) ;
        F1 ← 1.0;
        LAM ← 2.84   ;
        HAFPI ← 1.570796327;
        PI ← 3.141592654;
        S1[0,0] ← 35.0 ;
        S3[0,0] ← S2[0,0] ← 21.0 ;
        M[0,0] ← 160.0 ;
        X[0,0] ← 220.0 ;
        N1 ← 15    ;
        N2 ← 10    ;
        NM ← 150      ;
        NX ← 100      ;
        I1 ← I3 ← I5 ← 1;
        I2 ← I4 ← -1;
BEGIN
        REAL FM;
        IF NM MOD 2 = 0 THEN NM ← NM - 1 ;
        FM ← F1 / 10.0;
```

```
          FOR J ← -NM STEP 2 UNTIL NM DO
BEGIN
          K ← 1 + (J + NM) DIV 2 ;
          M[0,K] ←  J × FM;
          M[1,K] ← 0.0;
          M[2,K] ← -2.0 /(PI × J);
END;
          M[1,0] ← K;
END;
          PRINT(M);
BEGIN
          REAL F3,ANG,PI5,CO1,CO2;
          LABEL EXX;
          F3 ← F1 / 5.0;
          PI5 ← PI / 5.0;
          K ← 0 ;
          FOR J ← -NX STEP 1 UNTIL NX DO
BEGIN
          IF J MOD 5 = 0 THEN
BEGIN
          IF J = 0 THEN
BEGIN
          K ← K + 1 ;
          X[0,K] ← 0.0 ;
          X[1,K] ← ( I1 + I2 + I3 + I4 + I5 ) / 5.0 ;
          X[2,K] ← 0.0 ;
END;
          GO TO EXX ;
END;
          K ← K + 1 ;
          ANG ← SIN(J × PI5) / (J × PI);
          CO1 ← I1×COS(J×PI5) + I2×COS(3.0×J×PI5)
               +I3×COS(J×PI) + I4×COS(7.0×J×PI5)
                + I5×COS(9.0×J×PI5)  ;
          CO2 ← -(I1×SIN(J×PI5) + I2×SIN(3.0×J×PI5)
               + I4×SIN(7.0×J×PI5) + I5×SIN(9.0×J×PI5) ) ;
```

```
        X[0,K] ← J × F3;
        X[1,K] ← CO1 × ANG;
        X[2,K] ← CO2 × ANG;
EXX:
END;
        X[1,0] ← K;
END;
        PRINT(X);
        LAM ← 2.8407;
        FOR J ← -N1 STEP 1 UNTIL N1 DO
BEGIN
        COEF ← JAY( J,LAM) ;
        ARG ← LAM -(HAFPI × J);
        K ← J + N1 + 1 ;
        S1[0,K] ←  J × F1 ;
        S1[1,K] ← COEF × COS(ARG);
        S1[2,K] ← COEF × SIN(ARG);
END;
        S1[1,0] ← K;
        PRINT(S1);
BEGIN
        REAL HLAM;
        HLAM ← LAM / 2.0;
        FOR J ← -N2 STEP 1 UNTIL N2 DO
BEGIN
        COEF ← JAY( J,HLAM);
        ARG ← HLAM -( J × HAFPI);
        K ← J + N2 + 1;
        S2[0,K] ← S3[0,K] ← 2.0 ×  J × F1;
        S2[1,K] ← COEF × COS(ARG);
        S3[2,K] ← COEF × SIN(ARG);
        S2[2,K] ← S3[1,K] ← 0.0;
END;
        S2[1,0] ← S3[1,0] ← K;
END;
        PRINT(S2);
```

```
        PRINT(S3);
BEGIN
        ARRAY AR1[0:2,0:100],AR2[0:2,0:800];
        AR1[0,0] ← 100.0 ;
        AR2[0,0] ← 800.0 ;
        CONVOLVE(S1,S2,AR1,15.0);
        CONVOLVE(M,X,AR2,15.0);
        PRINT(AR2);
BEGIN
        ARRAY AR3[0:2,0:600];
        AR3[0,0] ← 600.0;
        CONVOLVE(AR2,S1,AR3,15.0);
        CONVOLVE(AR3,S3,AR2,15.0);
END;
        SUM(AR1,AR2);
BEGIN   ARRAY AR4[0:1,0:800];
        REAL MAX;
        LIST LST1(FOR J ← 1 STEP 1 UNTIL K DO [ J,AR2[0,J],AR2[1,J],
           AR2[2,J],SQRT(AR4[0,J]),4.3429448 × LN(AR4[0,J] / MAX),
                 AR4[1,J] ]);
        AR4[1,0] ← 0.0;
        MAX ← 0.0;
        K ← AR2[1,0];
        FOR J ← 1 STEP 1 UNTIL K DO
BEGIN
        AR4[0,J] ←       (AR2[1,J]×AR2[1,J])+(AR2[2,J]×AR2[2,J]);
        AR4[1,J] ← AR4[1,J-1] + AR4[0,J];
        IF AR4[0,J] > MAX THEN MAX ← AR4[0,J];
END;
        WRITE (PRT,FMT1,LST1);
END;
END;
EXIT:
        PRINTIME;
END.
```

LINE NO.	FREQUENCY, KILOHERTZ	COMPLEX COEFFICIENTS REAL	IMAGINARY	AMPLITUDE COEFFICIENT	DECIBELS REL TO MAX	CUMMULATIVE POWER
1	-15.000	1.237789E-05	3.988821E-05	4,176460E-05	-82,25	1,744282E-09
2	-14.900	1.682051E-04	-1.177114E-05	1,686165E-04	-70,13	3,017579E-08
3	-14.700	6.977535E-05	-5.148082E-06	6,996501E-05	-77,77	3,507089E-08
4	-14.500	2.215106E-04	8.722529E-04	8,999401E-04	-55,58	8,449630E-07
5	-14.300	-8.673926E-07	1.153645E-06	1,443352E-06	-111,48	8,449651E-07
6	-14.100	2.818176E-05	5.604068E-06	2,873355E-05	-85,50	8,457908E-07
7	-14.000	-1.327309E-04	4.118833E-05	1,389747E-04	-71,81	8,651047E-07
8	-13.900	1.427427E-04	3.730498E-04	3,994266E-04	-62,64	1,024646E-06
9	-13.700	5.699046E-05	1.547090E-04	1,648720E-04	-70,32	1,051829E-06
10	-13.500	-1.095032E-03	-4.360305E-03	4,495704E-03	-41,61	2,126318E-05
11	-13.300	-1.034872E-06	-3.760813E-06	3,900600E-06	-102,84	2,126320E-05
12	-13.100	2.937035E-05	5.409546E-05	6,155433E-05	-78,88	2,126699E-05
13	-13.000	-7.705669E-05	-2.483180E-04	2,5999[illegible]E-04	-66,37	2,133459E-05
14	-12.900	4.255246E-04	-7.393865E-05	4,319005E-04	-61,96	2,152113E-05
15	-12.700	1.740143E-04	-3.588857E-05	1,776765E-04	-69,67	2,155269E-05
16	-12.500	-5.316299E-03	-2.309330E-03	5,796209E-03	-39,40	5,514873E-05
17	-12.300	-4.519054E-06	8.068590E-07	4,590520E-06	-101,43	5,514875E-05
18	-12.100	6.846659E-05	6.549636E-06	6,877915E-05	-77,92	5,515348E-05
19	-12.000	5.396267E-05	-1.674541E-05	5,650114E-05	-79,62	5,515667E-05
20	-11.900	-2.227243E-05	-2.903806E-04	2,912335E-04	-65,38	5,524149E-05
21	-11.700	-1.705254E-05	-1.232575E-04	1,244315E-04	-72,77	5,525697E-05
22	-11.500	-5.237189E-03	2.813899E-03	5,945265E-03	-39,18	9,060315E-05
23	-11.300	1.390824E-07	3.081173E-06	3,084310E-06	-104,88	9,060316E-05
24	-11.100	2.136103E-05	-3.479791E-05	4,083121E-05	-82,45	9,060483E-05
25	-11.000	-4.601592E-04	-1.482880E-03	1,552636E-03	-50,84	9,301550E-05
26	-10.900	-2.182115E-04	2.264126E-05	2,193830E-04	-67,84	9,306363E-05
27	-10.700	-9.542201E-05	1.186991E-05	9,615745E-05	-75,01	9,307288E-05
28	-10.500	-1.421296E-03	-8.591088E-04	1,660768E-03	-50,26	9,583103E-05
29	-10.300	8.628470E-07	-6.659132E-07	1,089929E-06	-113,92	9,583103E-05
30	-10.100	-2.323532E-05	-8.890539E-06	2,487614E-05	-86,75	9,583165E-05
31	-10.000	6.022715E-03	-1.868936E-03	6,306031E-03	-38,67	1,355977E-04
32	-9.900	-4.379312E-05	-7.418812E-05	8,614937E-05	-75,96	1,356051E-04
33	-9.700	-1.923762E-05	-2.930616E-05	3,505619E-05	-83,77	1,356063E-04
34	-9.500	1.034043E-03	1.541237E-03	1,855979E-03	-49,29	1,390510E-04
35	-9.300	-1.204799E-06	7.140360E-07	1,400495E-06	-111,74	1,390510E-04
36	-9.100	-1.064552E-05	-1.469575E-05	1,814642E-05	-89,49	1,390513E-04
37	-9.000	4.037776E-03	1.301188E-02	1,362397E-02	-31,98	3,246639E-04
38	-8.900	-1.447759E-04	2.716688E-05	1,473027E-04	-71,30	3,246858E-04
39	-8.700	-6.188891E-05	1.382031E-05	6,341323E-05	-78,62	3,246896E-04
40	-8.500	-9.168006E-03	-6.109986E-03	1,101745E-02	-33,82	4,460739E-04
41	-8.300	-7.241012E-07	1.841830E-07	7,471585E-07	-117,20	4,460739E-04
42	-8.100	-2.288231E-05	-2.070005E-06	2,297575E-05	-87,44	4,460744E-04
43	-8.000	-1.516953E-02	4.707325E-03	1,588312E-02	-30,65	6,983479E-04
44	-7.900	5.063177E-06	8.943715E-05	8,958035E-05	-75,62	6,983559E-04
45	-7.700	1.447697E-06	3.632305E-05	3,635189E-05	-83,45	6,983572E-04

LINE NO.	FREQUENCY, KILOHERTZ	COMPLEX COEFFICIENTS REAL	IMAGINARY	AMPLITUDE COEFFICIENT	DECIBELS REL TO MAX	CUMMULATIVE POWER
46	-7.500	2.585601E-02	-4.023185E-02	4.782400E-02	-21.07	2.985492E-03
47	-7.300	-2.596241E-06	-2.618318E-06	3.687283E-06	-103.33	2.985492E-03
48	-7.100	-6.354128E-06	1.056765E-05	1.233087E-05	-92.85	2.985492E-03
49	-7.000	2.020104E-03	6.509858E-03	6.816089E-03	-37.99	3.031951E-03
50	-6.900	3.856187E-05	-2.503180E-06	3.864303E-05	-82.92	3.031953E-03
51	-6.700	1.629902E-05	-3.707308E-06	1.671532E-05	-90.20	3.031953E-03
52	-6.500	7.428407E-02	3.446433E-02	8.188964E-02	-16.40	9.737866E-03
53	-6.300	-1.048939E-06	-1.719450E-06	2.014145E-06	-108.58	9.737866E-03
54	-6.100	2.676007E-06	2.812943E-06	3.882481E-06	-102.88	9.737866E-03
55	-6.000	-8.107259E-02	2.515801E-02	8.488633E-02	-16.09	1.694356E-02
56	-5.900	3.755673E-09	-5.717614E-06	5.717615E-06	-99.52	1.694356E-02
57	-5.700	1.944233E-07	-2.439653E-06	2.447387E-06	-106.89	1.694358E-02
58	-5.500	-1.949369E-02	6.085681E-02	6.390270E-02	-18.55	2.102711E-02
59	-5.300	2.919302E-07	5.168825E-07	5.936251E-07	-119.19	2.102711E-02
60	-5.100	4.307561E-07	5.565612E-07	7.037835E-07	-117.72	2.102711E-02
61	-5.000	-5.417711E-02	-1.745877E-01	1.828005E-01	-9.43	5.444314E-02
62	-4.900	3.319673E-06	-3.674363E-07	3.339945E-06	-104.19	5.444314E-02
63	-4.700	2.197054E-06	-3.031935E-07	2.217875E-06	-107.75	5.444314E-02
64	-4.500	5.085858E-02	-3.026012E-03	5.094852E-02	-20.52	5.703889E-02
65	-4.300	9.336752E-07	1.456620E-07	9.449692E-07	-115.16	5.703889E-02
66	-4.100	7.167095E-07	5.322509E-07	8.927282E-07	-115.65	5.703889E-02
67	-4.000	2.128127E-01	-6.603888E-02	2.228236E-01	-7.71	1.066893E-01
68	-3.900	-3.360509E-07	-2.765980E-06	2.786320E-06	-105.76	1.066893E-01
69	-3.700	1.277787E-06	1.132933E-06	1.707711E-06	-110.02	1.066893E-01
70	-3.500	-9.305068E-02	1.677462E-01	1.918260E-01	-9.01	1.434865E-01
71	-3.300	1.564493E-06	2.232672E-06	2.726255E-06	-105.95	1.434865E-01
72	-3.100	2.854698E-07	-3.359041E-07	4.408226E-07	-121.78	1.434865E-01
73	-3.000	6.245051E-02	2.012490E-01	2.107160E-01	-8.19	1.878877E-01
74	-2.900	-1.414904E-06	1.666902E-07	1.424689E-06	-111.59	1.878877E-01
75	-2.700	2.435261E-06	1.771814E-06	3.011614E-06	-105.09	1.878877E-01
76	-2.500	-2.091076E-01	-1.849316E-01	2.791517E-01	-5.75	2.658134E-01
77	-2.300	2.998926E-06	1.429597E-06	3.322244E-06	-104.24	2.658134E-01
78	-2.100	-1.772960E-07	-3.919815E-07	4.302131E-07	-121.99	2.658134E-01
79	-2.000	7.518131E-02	-2.332986E-02	7.871792E-02	-16.74	2.720099E-01
80	-1.900	-5.897785E-08	6.489287E-08	8.768963E-08	-135.81	2.720099E-01
81	-1.700	2.267367E-06	-3.466185E-07	2.293708E-06	-107.45	2.720099E-01
82	-1.500	-1.783798E-02	-2.435998E-01	2.442520E-01	-6.91	3.316689E-01
83	-1.300	2.240100E-06	-3.970262E-07	2.275011E-06	-107.53	3.316689E-01
84	-1.100	-1.101362E-07	-1.249525E-07	1.665626E-07	-130.23	3.316689E-01
85	-1.000	3.011165E-02	9.703588E-02	1.016006E-01	-14.53	3.419916E-01
86	-0.900	-6.343110E-08	-1.362266E-07	1.502704E-07	-131.13	3.419916E-01
87	-0.700	1.109820E-07	2.776401E-07	2.990000E-07	-125.15	3.419916E-01
88	-0.500	-9.264507E-03	1.078603E-01	1.082575E-01	-13.98	3.537113E-01
89	-0.300	1.480750E-07	3.555705E-07	3.851709E-07	-122.95	3.537113E-01
90	-0.100	-6.653480E-09	-4.045506E-08	4.099854E-08	-142.41	3.537113E-01

LINE NO.	FREQUENCY, KILOHERTZ	COMPLEX COEFFICIENTS REAL	IMAGINARY	AMPLITUDE COEFFICIENT	DECIBELS REL TO MAX	CUMMULATIVE POWER
91	0,000	5.167584E-01	-1.603577E-01	5,410673E-01	0.00	6,464651E-01
92	0,100	6.655782E-09	4.045533E-08	4,099918E-08	-142,41	6,464651E-01
93	0,300	-1.480727E-07	-3.555712E-07	3,851706E-07	-122,95	6,464651E-01
94	0,500	9.264507E-03	-1.078603E-01	1,082575E-01	-13,98	6,581848E-01
95	0,700	-1.109820E-07	-2.776403E-07	2,990003E-07	-125,15	6,581848E-01
96	0,900	6.343217E-08	1.362254E-07	1,502697E-07	-131,13	6,581848E-01
97	1,000	3.011165E-02	9.703588E-02	1,016006E-01	-14,53	6,6[illegible]5075E-01
98	1,100	1.101377E-07	1.249514E-07	1,665628E-07	-130,23	6,68[illegible]075E-01
99	1,300	-2.240096E-06	3.970250E-07	2,275007E-06	-107,53	6,685[illegible]75E-01
100	1,500	1.783798E-02	2.435998E-01	2,442520E-01	-6,91	7,2816[illegible]E-01
101	1,700	-2.257368E-06	3.466202E-07	2,293710E-06	-107,45	7,281665E-01
102	1,900	5.897562E-08	-6.489306E-08	8,768827E-08	-135,81	7,281665E-01
103	2,000	7.518131E-02	-2.332986E-02	7,871792E-02	-1[illegible],74	7,343630[illegible]-01
104	2,100	1.772937E-07	3.919828E-07	4,302134E-07	-121,99	7,34363[illegible]-01
105	2,300	-2.998926E-06	-1.429598E-06	3,322244E-06	-104,24	7,343[illegible]0E-01
106	2,500	2.091076E-01	1.849316E-01	2,791517E-01	-5,75	[illegible],122887E-01
107	2,700	-2.435264E-06	-1.771812E-06	3,011616E-06	-105,09	8,122887E-01
108	[illegible]	1.414903E-06	-1.666890E-07	1,424688E-06	-111,59	8,122887E-01
109	3,000	6.245051E-02	2.012490E-01	2,107160E-01	-8,19	8,566899E-01
110	3,100	-2.854711E-07	3.359066E-07	4,408254E-07	-121,78	8,566899E-01
111	3,300	-1.564493E-06	-2.232671E-06	2,726254E-06	-105,95	8,566899E-01
112	3,500	9.305068E-02	-1.677462E-01	1,918260E-01	-9,01	8,934871E-01
113	3,700	-1.277787E-06	-1.132932E-06	1,707711E-06	-110,02	8,934871E-01
114	3,900	3.360517E-07	2.765980E-06	2,786320E-06	-105,76	8,934871E-01
115	4,000	2.128127E-01	-6.603888E-02	2,228236E-01	-7,71	9,431375E-01
116	4,100	-7.167096E-07	-5.322503E-07	8,927279E-07	-115,65	9,431375E-01
117	4,300	-9.336757E-07	-1.456603E-07	9,449694E-07	-115,16	9,431375E-01
118	4,500	-5.085858E-02	3.026012E-03	5,094852E-02	-20,52	9,457333E-01
119	4,700	-2.197054E-06	3.031939E-07	2,217876E-06	-107,75	9,457333E-01
120	4,900	-3.319674E-06	3.674380E-07	3,339947E-06	-104,19	9,457333E-01
121	5,000	-5.417711E-02	-1.745877E-01	1,828005E-01	-9,43	9,791493E-01
122	5,100	-4.307569E-07	-5.565596E-07	7,037827E-07	-117,72	9,791493E-01
123	5,300	-2.919318E-07	-5.168818E-07	5,936253E-07	-119,19	9,791493E-01
124	5,500	1.949369E-02	-6.085681E-02	6,390270E-02	-18,55	9,832328E-01
125	5,700	-1.944241E-07	2.439653E-06	2,447388E-06	-106,89	9,832328E-01
126	5,900	-3.755226E-09	5.717614E-06	5,717615E-06	-99,52	9,832328E-01
127	6,000	-8.107259E-02	2.515801E-02	8,488633E-02	-16,09	9,904385E-01
128	6,100	-2.676008E-06	-2.812942E-06	3,882481E-06	-102,88	9,904385E-01
129	6,300	1.048940E-06	1.719451E-06	2,014[illegible]46E-06	-108,58	9,904385E-01
130	6,500	-7.428407E-02	-3.446433E-02	8,188964E-02	-16,40	9,971444E-01
131	6,700	-1.629901E-05	3.707308E-06	1,671532E-05	-90,20	9,971444E-01
132	6,900	-3.856187E-05	2.503178E-06	3,864303E-05	-82,92	9,971444E-01
133	7,000	2.020104E-03	6.509858E-03	6,816089E-03	-37,99	9,971909E-01
134	7,100	6.354123E-06	-1.056767E-05	1,233087E-05	-92,85	9,971909E-01
135	7,300	2.596240E-06	2.618315E-06	3,687281E-06	-103,33	9,971909E-01

LINE NO.	FREQUENCY, KILOHERTZ	COMPLEX COEFFICIENTS REAL	IMAGINARY	AMPLITUDE COEFFICIENT	DECIBELS REL TO MAX	CUMMULATIVE POWER
136	7.500	-2.585601E-02	4.023185E-02	4.782400E-02	-21.07	9.994780E-01
137	7.700	-1.447699E-06	-3.632305E-05	3.635189E-05	-83.45	9.994780E-01
138	7.900	-5.063183E-06	-8.943716E-05	8.958036E-05	-75.62	9.994781E-01
139	8.000	-1.516953E-02	4.707325E-03	1.588312E-02	-30.65	9.997303E-01
140	8.100	2.288232E-05	2.069988E-06	2.297576E-05	-87.44	9.997303E-01
141	8.300	7.241033E-07	-1.841859E-07	7.471614E-07	-117.20	9.997303E-01
142	8.500	9.168006E-03	6.109986E-03	1.101745E-02	-33.82	9.998517E-01
143	8.700	6.188891E-05	-1.382031E-05	6.341324E-05	-78.62	9.998517E-01
144	8.900	1.447759E-04	-2.716690E-05	1.473027E-04	-71.30	9.998517E-01
145	9.000	4.037776E-03	1.301188E-02	1.362397E-02	-31.98	1.000037E+00
146	9.100	1.064555E-05	1.469577E-05	1.814644E-05	-89.49	1.000037E+00
147	9.300	1.204802E-06	-7.140351E-07	1.400498E-06	-111.74	1.000037E+00
148	9.500	-1.034043E-03	-1.541237E-03	1.855979E-03	-49.29	1.000041E+00
149	9.700	1.923762E-05	2.930616E-05	3.505620E-05	-83.77	1.000041E+00
150	9.900	4.379314E-05	7.418813E-05	8.614939E-05	-75.96	1.000041E+00
151	10.000	6.022715E-03	-1.868936E-03	6.306031E-03	-38.67	1.000081E+00
152	10.100	2.323533E-05	8.890554E-06	2.487816E-05	-86.75	1.000081E+00
153	10.300	-8.628471E-07	6.659154E-07	1.089930E-06	-113.92	1.000081E+00
154	10.500	1.421296E-03	8.591087E-04	1.660768E-03	-50.26	1.000083E+00
155	10.700	9.542201E-05	-1.186990E-05	9.615745E-05	-75.01	1.000083E+00
156	10.900	2.182115E-04	-2.264124E-05	2.193830E-04	-67.84	1.000083E+00
157	11.000	-4.601592E-04	-1.482880E-03	1.552636E-03	-50.84	1.000086E+00
158	11.100	-2.136100E-05	3.479800E-05	4.083128E-05	-82.45	1.000086E+00
159	11.300	-1.390794E-07	-3.081160E-06	3.084297E-06	-104.88	1.000086E+00
160	11.500	5.237189E-03	-2.813899E-03	5.945265E-03	-39.18	1.000121E+00
161	11.700	1.785255E-05	1.232575E-04	1.244315E-04	-72.77	1.000121E+00
162	11.900	2.227245E-05	2.903807E-04	2.912336E-04	-65.38	1.000121E+00
163	12.000	5.396267E-05	-1.674540E-05	5.650114E-05	-79.62	1.000121E+00
164	12.100	-6.846663E-05	-6.549524E-06	6.877918E-05	-77.92	1.000121E+00
165	12.300	4.519049E-06	-8.068444E-07	4.590512E-06	-101.43	1.000121E+00
166	12.500	5.316299E-03	2.309329E-03	5.796209E-03	-39.40	1.000155E+00
167	12.700	-1.740143E-04	3.588858E-05	1.776765E-04	-69.67	1.000155E+00
168	12.900	-4.255246E-04	7.393876E-05	4.319006E-04	-61.96	1.000155E+00
169	13.000	-7.705669E-05	-2.483180E-04	2.599991E-04	-66.37	1.000155E+00
170	13.100	-2.937042E-05	-5.409542E-05	6.155433E-05	-78.88	1.000155E+00
171	13.300	1.034863E-06	3.760819E-06	3.900602E-06	-102.84	1.000155E+00
172	13.500	1.095033E-03	4.360305E-03	4.495704E-03	-41.61	1.000175E+00
173	13.700	-5.699047E-05	-1.54[illegible]0E-04	1.648720E-04	-70.32	1.000175E+00
174	13.900	-1.427427E-04	-3.730498E-04	3.994266E-04	-62.64	1.000176E+00
175	14.000	-1.327309E-04	4.118833E-05	1.389747E-04	-71.81	1.000176E+00
176	14.100	-2.818175E-05	-5.604054E-06	2.873354E-05	-85.50	1.000176E+00
177	14.300	8.673943E-07	-1.153644E-06	1.443352E-06	-111.48	1.000176E+00
178	14.500	-2.215107E-04	-8.722530E-04	8.999401E-04	-55.58	1.000176E+00
179	14.700	-6.977535E-05	5.148085E-06	6.996501E-05	-77.77	1.000176E+00
180	14.900	-1.682051E-04	1.177115E-05	1.686164E-04	-70.13	1.000176E+00

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B. Computer program listing and sample calculation for the S-band spectrum when the command data signal modulates the transmitter.

Listing of the ALGOL program for computing the spectrum out of the S-band transmitter when only the command data is modulating the transmitter. The listing is followed by a sample of the output which lists the carrier and the first two sideband groups. The calculations were run for alternating sub-bits, a peak frequency deviation of the subcarrier oscillator of 5 kHz, and a peak phase deviation of the S-band transmitter of 1.22 radians.

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```
% S-BAND SPECTRUM OF COMMAND DATA ONLY.
BEGIN
        LABEL EXIT;
        INTEGER J,K,N1,N2,NM,NY,I1,I2,I3,I4,I5,TM,Q,PGNO;
        REAL COEF,ARG,LAM,PI,F1,HAFPI,BETA,BETASQ,LAMDA,MAX;
        ALPHA RUNNO,RUNID;
        REAL ARRAY     S2,S3[0:2,0:85],M[0:2,0:160],
                   AR1,AR3[0:2,0:100],AR2[0:2,0:300],
                          S1[0:2,0:85] ;
        FILE OUT PRT 6(2,15);
        FORMAT FMTT(//"RUNNING TIME",X2,I4,X2,"SECONDS"//);
        LIST LSTT((TIME(2) - TM) DIV 60);
%   ****************************************************************
        REAL    PROCEDURE FACTORIAL(N);                                  F 1
        VALUE N; INTEGER N ; BEGIN INTEGER I;
        REAL F ;  F ← 1.0 ;                                              F 2 1
        FOR I ← 2 STEP 1 UNTIL N DO F ← I × F; FACTORIAL ← F END ;       F 3
%   ****************************************************************
        REAL PROCEDURE JAY(N,X);                                         J 1
        VALUE N,X ; INTEGER N ; REAL X ; BEGIN INTEGER   P,NPOS; REAL    J 2
        XSQ,   A,SUMA,F; LABEL RPT; NPOS←ABS(N); A←SUMA←P←1; XSQ←X×X;    J 3
    RPT: A ← - (XSQ × A)/(4.0 × P × (NPOS +P)); SUMA ← SUMA + A; P←P+1;  J 4
        IF ABS(A) > 1.0@-7 THEN GO TO RPT;                               J 5
        F ← (((SIGN(N)×X/2.0)*NPOS)×SUMA)/FACTORIAL(NPOS); JAY←F  END;   J 6
%   ****************************************************************
```

```
         PROCEDURE PRINT(A);    ARRAY A[0,0];
BEGIN    INTEGER I,K ;
         REAL SUMP,X,Y  ;
         ARRAY POWER[-1:999];
         FORMAT FMTM("LINE",X9,"FREQ",X14,"REAL",X13,"IMAG",X10,
                  "AMPLITUDE",X7,"SUM OF POWER"/
                     10(5(I4,5(X2,F15.8)/)/) );
         LIST LSTM(FOR I ← 0 STEP 1 UNTIL K DO
                  [I,A[0,I],A[1,I],A[2,I],
                  SQRT(POWER[I] - POWER[I-1]),
                                       POWER[I] ] ) ;
         K ← A[1,0] ;
         SUMP ← 0.0 ;
         POWER[-1] ← POWER[0] ← 0;
         FOR I ← 1 STEP 1 UNTIL K DO
BEGIN    X ← A[1,I] ;  Y ← A[2,I] ;
         SUMP     ← SUMP + X×X + Y×Y ;
         POWER[I] ← SUMP                                 END;
         WRITE (PRT,FMTM,LSTM);
         WRITE (PRT[PAGE]);
END PRINT;
%   *******************************************************************
         PROCEDURE CONVOLVE(A,B,C,F);                              C 1
         VALUE F; REAL F;          ARRAY A,B,C[0,0];               C 1 1
BEGIN    INTEGER I,J,K,L,ASTOP,BSTOP,CMAX,CSTOP,ILO,IHI,JLO,JHI;  C 2
         REAL FRQ,RE,IM,FA,RA,IA,RB,IB,FFF;                        C 2 1
         BOOLEAN SKIP1;                                            C 2 2
         LABEL L1;                                                 C 2 3
         CSTOP ← C[0,0] - 1.0 ;                                    C 2 2
         FOR I ← 1 STEP 1 UNTIL CSTOP + 1 DO                       C 3
         C[0,I] ← 999999999.0;                                     C 4
```

```
        CMAX ← 0; ASTOP ← A[1,0]; BSTOP ← B[1,0];                            C 5
        EFF ← -B[0,BSTOP] - F - 1@-6; ILO ← 1;                               C 5 1
        WHILE A[0,ILO] < EFF DO ILO ← ILO+1;                                 C 5 2
        EFF ← -B[0,1] + F + 1@-6; IHI ← ASTOP;                               C 5 3
        WHILE A[0,IHI] > EFF DO IHI ← IHI - 1; SKIP1 ← FALSE;                C 5 4
        FOR I ← ILO STEP 1 UNTIL IHI DO                                      C 6
BEGIN   FA ← A[0,I] ; RA ← A[1,I] ; IA ← A[2,I] ; K ← 1 ;                    C 6 1
        IF SKIP1 THEN GO TO L1;                                              C 6 2
        EFF ← -F - FA - 1@-6; JLO ← 1;                                       C 6 3
        WHILE B[0,JLO] < EFF DO JLO ← JLO + 1;                               C 6 4
        IF JLO = 1 THEN SKIP1 ← TRUE;                                        C 6 5
L1:     EFF ← F - FA + 1@-6; JHI ← BSTOP;                                    C 7
        WHILE B[0,JHI] > EFF DO JHI ← JHI - 1;                               C 7 1
        FOR J ← JLO STEP 1 UNTIL JHI DO                                      C 7 2
BEGIN   RB ← B[1,J] ; IB ← B[2,J] ;                                          C 8
        FRQ ← FA + B[0,J] ;                                                  C 8 1
        RE ← RA × RB - IA × IB ;                                             C 9
        IM ← RA × IB + IA × RB ;                                             C10
        WHILE FRQ > C[0,K] + 1.0@-6 DO K ← K + 1 ;                           C11
        IF ABS(FRQ - C[0,K]) < 1.0@-6 THEN                                   C12
BEGIN   C[1,K] ← C[1,K] + RE;  C[2,K] ← C[2,K] + IM;                 END     C13
ELSE BEGIN FOR L ← CMAX STEP -1 UNTIL K DO                                   C14
BEGIN   C[0,L+1] ← C[0,L];  C[1,L+1] ← C[1,L];  C[2,L+1] ← C[2,L] END;       C15
        CMAX ← CMAX + 1; C[0,K] ← FRQ; C[1,K] ← RE; C[2,K] ← IM;             C16
        IF CMAX > CSTOP       THEN
BEGIN   C[1,0] ← CMAX ;
        PRINT(C); GO TO EXIT  END ;
END; END; END;                                                               C17
        C[1,0] ← CMAX ;
END CONVOLVE;
%    ************************************************************
```

```
          PROCEDURE SUM(A,B);    ARRAY A,B[0,0];
BEGIN     INTEGER I,K,L,ASTOP,BMAX;
          ASTOP ← A[1,0]; BMAX ← B[1,0]; K ← B[0,0];
          FOR I ← BMAX +1 STEP 1 UNTIL K DO
BEGIN     B[0,I] ← 999999999.0; B[1,I] ← B[2,I] ← 0.0 ;           END;
          K ← 1 ; FOR I ← 1 STEP 1 UNTIL ASTOP DO
BEGIN     WHILE A[0,I] > B[0,K] DO K ← K + 1; IF A[0,I] = B[0,K] THEN
BEGIN     B[1,K] ← B[1,K] + A[1,I]; B[2,K] ← B[2,K] + A[2,I]      END
ELSE BEGIN FOR L ← BMAX STEP -1 UNTIL K DO
BEGIN     B[0,L+1] ← B[0,L]; B[1,L+1] ← B[1,L]; B[2,L+1] ← B[2,L] END;
          BMAX ← BMAX+1; B[0,K] ← A[0,I]; B[1,K]←A[1,I]; B[2,K]←A[2,I];
END; END; B[1,0] ← BMAX ;
END SUM;
%    ********************************************************************
          REAL PROCEDURE CNR(Q);
          VALUE Q; INTEGER Q;
BEGIN     REAL QSQ,TEMP,SUMA;
          INTEGER I;
          Q ← ABS(Q);    QSQ ← Q × Q;
          TEMP ← ((BETA/2)*Q) / FACTORIAL(Q);
          SUMA ← TEMP;
          FOR I ← Q+2 STEP 2 WHILE TEMP > 10-17 DO
BEGIN
          TEMP ← -(BETASQ / (I×I - QSQ)) × TEMP;
          SUMA ← SUMA + TEMP;
END;
          CNR ← SUMA
END CNR;
%    ********************************************************************
```

```
          PROCEDURE FOMEG(Q);   VALUE Q; INTEGER Q;
BEGIN     INTEGER I        ;          REAL C,TEMP       ;
          LABEL L1,L2,L3,L4,L5;
          SWITCH SW1 ← L1,L2,L3,L4;
          IF Q=0 THEN BEGIN AR2[0,1]←AR2[2,1]←0;AR2[1,0]←1;
                    AR2[1,1]←CNR(0); MAX←AR2[1,1]*2 END ELSE
BEGIN
          LAM ← LAMDA × Q;
          FOR J ← -N1 STEP 1 UNTIL N1 DO
BEGIN
          COEF ← JAY( J,LAM) ;
          ARG ← LAM -(HAFPI × J);
          K ← J + N1 + 1 ;
          S1[0,K] ←  J × F1 ;
          S1[1,K] ← COEF × COS(ARG);
          S1[2,K] ← COEF × SIN(ARG);
END;
          S1[1,0] ← K;
BEGIN
          REAL HLAM;
          HLAM ← LAM / 2.0;
          FOR J ← -N2 STEP 1 UNTIL N2 DO
BEGIN
          COEF ← JAY( J,HLAM);
          ARG ← HLAM -( J × HAFPI);
          K ← J + N2 + 1;
          S2[0,K] ← S3[0,K] ← 2.0 ×  J × F1;
          S2[1,K] ← COEF × COS(ARG);
          S3[2,K] ← COEF × SIN(ARG);
          S2[2,K] ← S3[1,K] ← 0.0;
END;
          S2[1,0] ← S3[1,0] ← K;
END;
```

```
            CONVOLVE(S1,S2,AR1,30,n);
            CONVOLVE(S1,S3,AR3,30,n);
            CONVOLVE(AR3,M,AR2,30,n);
            SUM(AR1,AR2);
            C ← CNR(Q);
            K ← AR2[1,0];
            GO TO SWIT(Q MOD 4) + 1];
L1:         FOR I ← 1 STEP 1 UNTIL K DO
     BEGIN
            AR2[1,I] ← C × AR2[1,I];
            AR2[2,I] ← C × AR2[2,I];
     END;   GO TO L5;
L2:         FOR I ← 1 STEP 1 UNTIL K DO
     BEGIN
            TEMP ← AR2[1,I];
            AR2[1,I] ← -C × AR2[2,I];
            AR2[2,I] ← C × TEMP;
     END;   GO TO L5;
L3:         C ← -C; GO TO L1;
L4:         C ← -C; GO TO L2;
L5:         FOR I ← 1 STEP 1 UNTIL K DO
            AR2[0,I] ← Q × 70.0 + AR2[0,I];
END;
END FOMEG;
%    ************************************************************************
```

```
          PROCEDURE OUTPUTRES(A);  ARRAY A[0,0];
BEGIN
          REAL     AMAX;
          INTEGER J,K,L,LIM,I,LO;
          ARRAY AR4[0:1,0:1000];
          FORMAT HD1(X19,"S-BAND SPECTRUM",X20,"RUN NUMBER ",A5,X1,A7,
                    X20,"PAGE NO.",I3//
                    "LINE",X3,"FREQUENCY,",X8,"COMPLEX COEFFICIENTS",
             X11,"AMPLITUDE",X6,"DECIBELS",X7,"CUMMULATIVE"/X1,"NO.",
                X3,"KILOHERTZ",X8,"REAL",X11,"IMAGINARY",X7,
                "COEFFICIENT",X4,"REL TO MAX",X9,"POWER"/),
             FMT1(9( 5(I4,X2,F9.3,3(X2,E15.6),X5,F7.2,X5,E15.6/)/)     );
          LIST LSTHD(RUNID,RUNNO,PGNO),
               LST1(FOR J + LO STEP 1 UNTIL LIM DO [ J,A[0,J],A[1,J],
                  A[2,J],SQRT(AR4[0,J]),IF AR4[0,J] < 1@-45 THEN 1@43
                        ELSE 4.3429448 x LN(AR4[0,J]/MAX),AR4[1,J]]);
          AR4[1,0] + 0;
          AMAX + A[1,0] + 1@-6;
          K + ENTIER(AMAX/45);
          I + AMAX MOD 45;
          FOR J + 1 STEP 1 UNTIL AMAX DO
BEGIN
          AR4[0,J] + (  A[1,J]*2 +   A[2,J]*2);
          AR4[1,J] + AR4[1,J-1] + AR4[0,J];
END;
          FOR L + 0 STEP 1 UNTIL K DO
BEGIN
          PGNO + PGNO + 1;
          LO + 45 x L + 1;
          LIM + IF L = K THEN LO+I-1 ELSE LO+44;
          WRITE (PRT,HD1,LSTHD);
          WRITE (PRT,FMT1,LST1);
          WRITE (PRT[PAGE]);
END;
END OUTPUTRES;
%    ************************************************************************
```

```
        WRITE (PRT[NO]) ;
        TM ← TIME(2) ;
        LAMDA ← 2.84   ;
        BETA ← 1.22;
        N1 ← 40    ;
        N2 ← 20    ;
        NM ← 150       ;
        S1[0,0] ← 85.0 ;
        S3[0,0] ← S2[0,0] ← 85.0 ;
        M[0,0] ← 160.0 ;
        AR1[0,0] ← 100;
        AR2[0,0] ← 300;
        AR3[0,0] ← 100;
        MAX ← 1;
        PGNO ← 0;
        RUNID ← " PRD ";  RUNNO ← "  1     ";
        I1 ← I3 ← I5 ← 1;
        I2 ← I4 ← -1;
        F1 ← 1.0;
        HAFPI ← 1.570796327;
        PI ← 3.141592654;
        BETASQ ← BETA × BETA;
BEGIN
        REAL FM;
        IF NM MOD 2 = 0 THEN NM ← NM - 1 ;
        FM ← F1 /  2.0;
        FOR J ← -NM STEP 2 UNTIL NM DO
BEGIN
        K ← 1 + (J + NM) DIV 2 ;
        M[0,K] ←  J × FM;
        M[1,K] ← 0.0;
        M[2,K] ← -2.0 /(PI × J);
END;
        M[1,0] ← K;
END;
```

```
        FOR Q ← 0 STEP 1 UNTIL 8 DO
BEGIN
        FOMEG(Q);
        OUTPUTRES(AR2);
END;
EXIT:
        WRITE(PRT,FMTT,LSTT); WRITE(PRT[PAGE]);
END.
```

S-BAND SPECTRUM RUN NUMBER PRO 1

LINE NO.	FREQUENCY, KILOHERTZ	COMPLEX COEFFICIENTS REAL	IMAGINARY	AMPLITUDE COEFFICIENT	DECIBELS REL TO MAX	CUMMULATIVE POWER
1	0.000	6.279000P-01	0.000000P+00	6.279000P-01	0.00	3.942584P-01

S-BAND SPECTRUM RUN NUMBER PRO 1

LINE NO.	FREQUENCY, KILOHERTZ	COMPLEX COEFFICIENTS REAL	IMAGINARY	AMPLITUDE COEFFICIENT	DECIBELS REL TO MAX	CUMMULATIVE POWER
1	40,000	-1.273782E-15	-4.094680E-15	4.288230E-15	-283.31	1.838892E-29
2	40.500	6.918276E-07	3.508770E-05	3.509452E-05	-85.05	1.231625E-09
3	41.000	-2.189613E-13	6.811497E-14	2.293114E-13	-248.75	1.231625E-09
4	41.500	8.223631E-07	3.891826E-05	3.892694E-05	-84.15	2.746932E-09
5	42.000	-4.545941E-13	-1.461331E-12	1.530407E-12	-232.26	2.746932E-09
6	42.500	9.835610E-07	4.332693E-05	4.333809E-05	-83.22	4.625122E-09
7	43.000	5.342225E-12	-1.661871E-12	5.594746E-12	-221.00	4.625122E-09
8	43.500	1.184134E-06	4.842686E-05	4.844133E-05	-82.25	6.971685E-09
9	44.000	2.639758E-12	8.485727E-12	8.886838E-12	-216.98	6.971685E-09
10	44.500	1.435712E-06	5.435871E-05	5.437766E-05	-81.25	9.928616E-09
11	45.000	3.395698E-11	-1.056341E-11	3.556209E-11	-204.94	9.928616E-09
12	45.500	1.754245E-06	6.129882E-05	6.132392E-05	-80.21	1.368924E-08
13	46.000	1.021707E-10	3.284364E-10	3.439613E-10	-185.23	1.368924E-08
14	46.500	2.161030E-06	6.947066E-05	6.950426E-05	-79.12	1.852008E-08
15	47.000	-1.396064E-09	4.342907E-10	1.462055E-09	-172.66	1.852008E-08
16	47.500	2.586889E-06	7.915702E-05	7.920259E-05	-77.98	2.479313E-08
17	48.000	-1.020270E-09	-3.279745E-09	3.434775E-09	-165.24	2.479313E-08
18	48.500	3.379311E-06	9.073374E-05	9.079665E-05	-76.80	3.303716E-08
19	49.000	-5.042196E-10	1.568537E-10	5.280535E-10	-181.50	3.303716E-08
20	49.500	4.258271E-06	1.046917E-04	1.047783E-04	-75.55	4.401565E-08
21	50.000	-1.367880E-08	-4.397167E-08	4.605016E-08	-142.69	4.401566E-08
22	50.500	5.428358E-06	1.215555E-04	1.216767E-04	-74.25	5.882087E-08
23	51.000	2.244647E-07	-6.982696E-08	2.350749E-07	-128.53	5.882093E-08
24	51.500	7.080505E-06	1.424151E-04	1.425910E-04	-72.88	7.915318E-08
25	52.000	2.005934E-07	6.448243E-07	6.753045E-07	-119.37	7.915357E-08
26	52.500	8.393824E-06	1.675496E-04	1.677597E-04	-71.46	1.072049E-07
27	53.000	-7.893931E-07	2.455661E-07	8.267069E-07	-117.61	1.072976E-07
28	53.500	1.462090E-05	1.963219E-04	1.968656E-04	-70.07	1.460536E-07
29	54.000	8.214777E-07	2.640710E-06	2.765533E-06	-107.12	1.460613E-07
30	54.500	2.635344E-05	2.462159E-04	2.476222E-04	-68.08	2.073781E-07
31	55.000	-1.975868E-05	6.146574E-06	2.069265E-05	-89.64	2.078063E-07
32	55.500	2.011573E-05	3.006599E-04	3.013321E-04	-66.38	2.986073E-07
33	56.000	-2.045737E-05	-6.576195E-05	6.887044E-05	-79.20	3.033504E-07
34	56.500	8.273452E-05	3.889792E-04	3.976806E-04	-63.97	4.615003E-07
35	57.000	1.230537E-04	-3.827980E-05	1.288703E-04	-73.75	4.781078E-07
36	57.500	-8.903536E-05	7.168270E-04	7.223353E-04	-58.78	9.998761E-07
37	58.000	8.325400E-06	2.676270E-05	2.802775E-05	-87.01	1.000662E-06
38	58.500	-6.380139E-04	2.011363E-04	6.689675E-04	-59.45	1.448179E-06
39	59.000	7.349763E-04	-2.286380E-04	7.697178E-04	-58.23	2.040645E-06
40	59.500	6.535598E-04	-3.138438E-04	7.250092E-04	-58.75	2.566283E-06
41	60.000	9.288079E-04	2.985732E-03	3.126864E-03	-46.06	1.234356E-05
42	60.500	-7.092991E-05	8.527741E-04	8.557189E-04	-57.31	1.307582E-05
43	61.000	-6.451657E-03	2.006995E-03	6.756620E-03	-39.36	5.872773E-05
44	61.500	3.450195E-03	-5.069050E-03	6.131811E-03	-40.21	9.632684E-05
45	62.000	-2.340065E-03	-7.522337E-03	7.877909E-03	-38.03	1.583883E-04

S-BAND SPECTRUM RUN NUMBER PRO 1

LINE NO.	FREQUENCY, KILOHERTZ	COMPLEX COEFFICIENTS REAL	IMAGINARY	AMPLITUDE COEFFICIENT	DECIBELS REL TO MAX	CUMMULATIVE POWER
46	62,500	1,977403E-02	1,250417E-02	2,339587E-02	-28,58	7,057549E-04
47	63,000	-3,228915E-03	1,004458E-03	3,381542E-03	-45,38	7,171897E-04
48	63,500	-1,715746E-02	3,689486E-02	4,068918E-02	-23,77	2,372799E-03
49	64,000	-1,251155E-02	-4,021943E-02	4,212055E-02	-23,47	4,146940E-03
50	64,500	-3,022598E-02	-9,649211E-03	3,172880E-02	-25,93	5,153657E-03
51	65,000	8,663192E-02	-2,694964E-02	9,072691E-02	-16,80	1,338503E-02
52	65,500	1,495754E-03	2,526457E-02	2,530881E-02	-27,89	1,402557E-02
53	66,000	3,285231E-02	1,056065E-01	1,105984E-01	-15,08	2,625758E-02
54	66,500	-8,332206E-02	-4,611881E-02	9,523397E-02	-16,38	3,532709E-02
55	67,000	-9,988671E-02	3,107297E-02	1,046082E-01	-15,57	4,626997E-02
56	67,500	9,178814E-02	-1,039222E-01	1,386539E-01	-13,12	6,549487E-02
57	68,000	1,160300E-02	3,729882E-02	3,906189E-02	-24,12	6,702070E-02
58	68,500	1,210048E-01	-8,896015E-03	1,213314E-01	-14,28	8,174200E-02
59	69,000	-4,831589E-02	1,503021E-02	5,059973E-02	-21,87	8,430233E-02
60	69,500	-5,354058E-02	-4,448337E-03	5,372505E-02	-21,35	8,718871E-02
61	70,000	7,978436E-02	2,564736E-01	2,685968E-01	-7,38	1,593330E-01
62	70,500	5,354058E-02	4,448337E-03	5,372505E-02	-21,35	1,622193E-01
63	71,000	-4,831589E-02	1,503021E-02	5,059973E-02	-21,87	1,647797E-01
64	71,500	-1,210048E-01	8,896015E-03	1,213314E-01	-14,28	1,795010E-01
65	72,000	1,160300E-02	3,729882E-02	3,906189E-02	-24,12	1,810268E-01
66	72,500	-9,178814E-02	1,039222E-01	1,386539E-01	-13,12	2,002517E-01
67	73,000	-9,988671E-02	3,107297E-02	1,046082E-01	-15,57	2,111946E-01
68	73,500	8,332206E-02	4,611881E-02	9,523397E-02	-16,38	2,202641E-01
69	74,000	3,285231E-02	1,056065E-01	1,105984E-01	-15,08	2,324961E-01
70	74,500	-1,495754E-03	-2,526457E-02	2,530881E-02	-27,89	2,331366E-01
71	75,000	8,663192E-02	-2,694964E-02	9,072691E-02	-16,80	2,413680E-01
72	75,500	3,022598E-02	9,649211E-03	3,172880E-02	-25,93	2,423747E-01
73	76,000	-1,251155E-02	-4,021943E-02	4,212055E-02	-23,47	2,441489E-01
74	76,500	1,715746E-02	-3,689486E-02	4,068918E-02	-23,77	2,458045E-01
75	77,000	-3,228915E-03	1,004458E-03	3,381542E-03	-45,38	2,458159E-01
76	77,500	-1,977403E-02	-1,250417E-02	2,339587E-02	-28,58	2,463633E-01
77	78,000	-2,340065E-03	-7,522337E-03	7,877909E-03	-38,03	2,464253E-01
78	78,500	-3,450195E-03	5,069050E-03	6,131811E-03	-40,21	2,464629E-01
79	79,000	-6,451657E-03	2,006996E-03	6,756620E-03	-39,36	2,465086E-01
80	79,500	7,092992E-05	-8,527741E-04	8,557189E-04	-57,31	2,465093E-01
81	80,000	9,288079E-04	2,985732E-03	3,126864E-03	-46,06	2,465191E-01
82	80,500	-6,535598E-04	3,138438E-04	7,250092E-04	-58,75	2,465196E-01
83	81,000	7,349763E-04	-2,286380E-04	7,697178E-04	-58,23	2,465202E-01
84	81,500	6,380139E-04	-2,011363E-04	6,689675E-04	-59,45	2,465207E-01
85	82,000	8,325399E-06	2,676270E-05	2,802775E-05	[illegible]	2,465207E-01
86	82,500	8,903536E-05	-7,168270E-04	7,223353E-04	-58,78	2,465212E-01
87	83,000	1,230537E-04	-3,827980E-05	1,288703E-04	-73,75	2,465212E-01
88	83,500	-8,273452E-05	-3,889792E-04	3,976806E-04	-63,97	2,465214E-01
89	84,000	-2,045737E-05	-6,576195E-05	6,887044E-05	-79,20	2,465214E-01
90	84,500	-2,011573E-05	-3,006599E-04	3,013321E-04	-66,38	2,465215E-01

S-BAND SPECTRUM RUN NUMBER PRO 1

LINE NO.	FREQUENCY, KILOHERTZ	COMPLEX COEFFICIENTS REAL	COMPLEX COEFFICIENTS IMAGINARY	AMPLITUDE COEFFICIENT	DECIBELS REL TO MAX	CUMMULATIVE POWER
91	85,000	-1,975868P-05	6,146574P-06	2,069265P-05	-89,64	2,465215P-01
92	85,500	-2,635344P-05	-2,462159P-04	2,476222P-04	-68,08	2,465215P-01
93	86,000	8,214777P-07	2,640710P-06	2,765533P-06	-107,12	2,465215P-01
94	86,500	-1,462090P-05	-1,963219P-04	1,968656P-04	-70,07	2,465216P-01
95	87,000	-7,893931P-07	2,455661P-07	8,267068P-07	-117,61	2,465216P-01
96	87,500	-8,393824P-06	-1,675496P-04	1,677597P-04	-71,46	2,465216P-01
97	88,000	2,005934P-07	6,448243P-07	6,753045P-07	-119,37	2,465218P-01
98	88,500	-7,080505P-06	-1,424151P-04	1,425910P-04	-72,88	2,465216P-01
99	89,000	2,244647P-07	-6,982696P-08	2,350749P-07	-128,53	2,465216P-01
100	89,500	-5,428358P-06	-1,215555P-04	1,216767P-04	-74,25	2,465216P-01
101	90,000	-1,367880P-08	-4,397167P-08	4,605016P-08	-142,69	2,465216P-01
102	90,500	-4,258271P-06	-1,046917P-04	1,047783P-04	-75,55	2,465216P-01
103	91,000	-5,042196P-10	1,568538P-10	5,280536P-10	-181,50	2,465216P-01
104	91,500	-3,379311P-06	-9,073374P-05	9,079665P-05	-76,80	2,465216P-01
105	92,000	-1,020270P-09	-3,279745P-09	3,434775P-09	-165,24	2,465216P-01
106	92,500	-2,686489P-06	-7,915702P-05	7,920259P-05	-77,98	2,465217P-01
107	93,000	-1,396064P-09	4,342907P-10	1,462055P-09	-172,66	2,465217P-01
108	93,500	-2,161030P-06	-6,947066P-05	6,950426P-05	-79,12	2,465217P-01
109	94,000	1,021707P-10	3,284364P-10	3,439613P-10	-185,23	2,465217P-01
110	94,500	-1,754245P-06	-6,129882P-05	6,132392P-05	-80,21	2,465217P-01
111	95,000	3,395698P-11	-1,056341P-11	3,556209P-11	-204,94	2,465217P-01
112	95,500	-1,435712P-06	-5,435871P-05	5,437766P-05	-81,25	2,465217P-01
113	96,000	2,639758P-12	8,485727P-12	8,886838P-12	-216,98	2,465217P-01
114	96,500	-1,184134P-06	-4,842686P-05	4,844133P-05	-82,25	2,465217P-01
115	97,000	5,342225P-12	-1,661871P-12	5,594746P-12	-221,00	2,465217P-01
116	97,500	-9,835610P-07	-4,332693P-05	4,333809P-05	-83,22	2,465217P-01
117	98,000	-4,545941P-13	-1,461331P-12	1,530407P-12	-232,26	2,465217P-01
118	98,500	-8,223631P-07	-3,891826P-05	3,892694P-05	-84,15	2,465217P-01
119	99,000	-2,189613P-13	6,811497P-14	2,293114P-13	-248,75	2,465217P-01
120	99,500	-6,918276P-07	-3,508770P-05	3,509452P-05	-85,05	2,465217P-01
121	100,000	-1,273782P-15	-4,094679P-15	4,288230P-15	-283,31	2,465217P-01

S-BAND SPECTRUM RUN NUMBER PRO 1

LINE NO.	FREQUENCY, KILOHERTZ	COMPLEX COEFFICIENTS REAL	COMPLEX COEFFICIENTS IMAGINARY	AMPLITUDE COEFFICIENT	DECIBELS REL TO MAX	CUMMULATIVE POWER
1	110.000	1.310331D-09	-9.025866D-10	1.591110D-09	-171.92	2.531631D-18
2	110.500	-2.295488D-05	8.940692D-07	2.297229D-05	-88.73	5.277261D-10
3	111.000	5.154415D-09	7.482929D-09	9.086375D-09	-156.79	5.277262D-10
4	111.500	-2.544801D-05	1.065636D-06	2.547031D-05	-87.84	1.176463D-09
5	112.000	-2.206528D-08	1.519907D-08	2.679344D-08	-147.40	1.176463D-09
6	112.500	-2.831017D-05	1.245027D-06	2.633753D-05	-86.91	1.979479D-09
7	113.000	-2.498385D-08	-3.627034D-08	4.404237D-08	-143.08	1.979481D-09
8	113.500	-3.150498D-05	1.549437D-06	3.154306D-05	-85.98	2.974445D-09
9	114.000	-1.241879D-08	8.554350D-09	1.507990D-08	-152.39	2.974446D-09
10	114.500	-3.552570D-05	2.152847D-06	3.559087D-05	-84.93	4.241156D-09
11	115.000	-2.136128D-07	-3.101126D-07	3.765638D-07	-124.44	4.241298D-09
12	115.500	-4.036111D-05	2.173400D-06	4.041958D-05	-83.83	5.875040D-09
13	116.000	1.161985D-06	-8.004020D-07	1.410976D-06	-112.97	5.877031D-09
14	116.500	-4.530676D-05	3.191270D-06	4.541901D-05	-82.81	7.939918D-09
15	117.000	1.755345D-06	2.548325D-06	3.094382D-06	-106.15	7.949493D-09
16	117.500	-5.570161D-05	2.627346D-06	5.576354D-05	-81.03	1.105007D-08
17	118.000	-2.590859D-06	1.784644D-06	3.146029D-06	-106.00	1.106896D-08
18	118.500	-5.538647D-05	-9.204238D-06	5.713276D-05	-80.82	1.433312D-08
19	119.000	3.610607D-06	5.241703D-06	6.364898D-06	-99.88	1.437363D-08
20	119.500	-4.234224D-05	1.005053D-05	4.351410D-05	-83.19	1.626710D-08
21	120.000	-3.337917D-05	2.299235D-05	4.053168D-05	-83.80	1.790992D-08
22	120.500	-8.193145D-05	2.554384D-05	8.582104D-05	-77.29	2.527517D-08
23	121.000	-6.231368D-05	-9.046397D-05	1.098486D-04	-75.14	3.734190D-08
24	121.500	-2.846989D-05	2.032487D-05	3.498050D-05	-85.08	3.856553D-08
25	122.000	1.464567D-04	-1.008828D-04	1.778395D-04	-70.96	7.019242D-08
26	122.500	-1.631060D-04	3.120909D-04	3.521425D-04	-65.02	1.941967D-07
27	123.000	4.955811D-05	7.194605D-05	8.736270D-05	-77.13	2.018290D-07
28	123.500	-8.276955D-04	-1.140890D-04	8.355215D-04	-57.52	8.999252D-07
29	124.000	3.915518D-04	-2.697099D-04	4.754537D-04	-62.42	1.125981D-06
30	124.500	2.507581D-05	-9.466242D-04	9.469562D-04	-56.43	2.022708D-06
31	125.000	1.020103D-03	1.480936D-03	1.798272D-03	-50.86	5.256491D-06
32	125.500	9.441200D-05	7.989418D-05	1.236799D-04	-74.11	5.271788D-06
33	126.000	-2.949755D-03	2.031860D-03	3.581831D-03	-44.88	1.810130D-05
34	126.500	2.395924D-04	-2.467200D-03	2.478806D-03	-48.07	2.424578D-05
35	127.000	-2.378151D-03	-3.452484D-03	4.192284D-03	-43.51	4.182103D-05
36	127.500	7.418473D-03	1.472395D-03	7.563180D-03	-38.38	9.902271D-05
37	128.000	5.059954D-04	-3.485414D-04	6.144204D-04	-60.19	9.940023D-05
38	128.500	-2.696746D-03	1.301067D-02	1.328721D-02	-33.49	2.759502D-04
39	129.000	-5.254642D-03	-7.628434D-03	9.263059D-03	-36.62	3.617545D-04
40	129.500	-1.300252D-02	-2.289796D-03	1.320261D-02	-33.54	5.360633D-04
41	130.000	1.876804D-02	-1.292786D-02	2.278966D-02	-28.80	1.055432D-03
42	130.500	-3.516751D-04	-1.047293D-03	1.104762D-03	-55.09	1.056653D-03
43	131.000	1.783271D-02	2.588865D-02	3.143609D-02	-26.01	2.044880D-03
44	131.500	-1.988915D-02	-3.708674D-03	2.023198D-02	-29.84	2.454214D-03
45	132.000	-1.961291D-02	1.350983D-02	2.381558D-02	-28.42	3.021375D-03

S-BAND SPECTRUM RUN NUMBER PRO 1

LINE NO.	FREQUENCY, KILOHERTZ	COMPLEX COEFFICIENTS REAL	IMAGINARY	AMPLITUDE COEFFICIENT	DECIBELS REL TO MAX	CUMMULATIVE POWER
46	132,500	4,581620E-03	-3,543691E-02	3,573186E-02	-24,90	4,298162E-03
47	133,000	-1,029922E-03	-1,495190E-03	1,815580E-03	-50,78	4,301458E-03
48	133,500	3,162682E-02	7,249838E-03	3,244713E-02	-25,73	5,354274E-03
49	134,000	-8,793530E-03	6,057188E-03	1,067781E-02	-35,39	5,468290E-03
50	134,500	-6,929098E-03	1,426929E-02	1,586269E-02	-31,95	5,719915E-03
51	135,000	-5,774684E-03	-8,383405E-03	1,017981E-02	-35,80	5,823543E-03
52	135,500	-5,877863E-03	8,749725E-03	1,054073E-02	-35,50	5,934650E-03
53	136,000	-7,562520E-03	5,209239E-03	9,183021E-03	-36,70	6,018978E-03
54	136,500	6,540222E-03	-1,046319E-02	1,233908E-02	-34,13	6,171231E-03
55	137,000	-2,359577E-02	-3,425519E-02	4,159541E-02	-23,58	7,901409E-03
56	137,500	2,318431E-02	1,7166[illegible]E-02	2,884769E-02	-26,76	8,733599E-03
57	138,000	-7,168609E-03	4,93790[illegible]E-03	8,704703E-03	-37,16	8,809370E-03
58	138,500	2,217225E-02	2,97121[illegible]E-02	3,707320E-02	-24,58	1,018379E-02
59	139,000	-7,033949E-03	-1,021154E-02	1,239968E-02	-34,09	1,033754E-02
60	139,500	6,5566[illegible]E-04	-2,167680E-02	2,168671E-02	-29,23	1,080786E-02
61	140,000	-5,790949E-02	3,988940E-02	7,031837E-02	-19,02	1,575253E-02
62	140,500	-[illegible],556661E-04	2,167680E-02	2,168671E-02	-29,23	1,622284E-02
63	141,000	-7,0[illegible]3949E-03	-1,021154E-02	1,239968E-02	-34,09	1,637660E-02
64	141,500	-2,21[illegible]225E-02	-2,971218E-02	3,707320E-02	-24,58	1,775102E-02
65	142,000	-7,168609E-03	4,937904E-03	8,704703E-03	-37,16	1,782679E-02
66	142,500	-2,31843[illegible]E-02	-1,716615E-02	2,884769E-02	-26,76	1,865898E-02
67	143,000	-2,35957[illegible]E-02	-3,425519E-02	4,159541E-02	-23,58	2,038916E-02
68	143,500	-6,540222E-03	1,046319E-02	1,233908E-02	-34,13	2,054141E-02
69	144,000	-7,562520E-03	5,209239E-03	9,183021E-03	-36,70	2,062574E-02
70	144,500	5,877863E-03	-8,749725E-03	1,054073E-02	-35,50	2,073685E-02
71	145,000	-5,774684E-03	-8,383405E-03	1,017981E-02	-35,80	2,084047E-02
72	145,500	6,929098E-03	-1,426929E-02	1,586269E-02	-31,95	2,109210E-02
73	146,000	-8,793530E-03	6,057188E-03	1,067781E-02	-35,39	2,120611E-02
74	146,500	-3,162682E-02	-7,249838E-03	3,244713E-02	-25,73	2,225893E-02
75	147,000	-1,029922E-03	-1,495190E-03	1,815580E-03	-50,78	2,226223E-02
76	147,500	-4,581620E-03	3,543691E-02	3,573186E-02	-24,90	2,353899E-02
77	148,000	-1,961291E-02	1,350983E-02	2,381558E-02	-28,42	2,410618E-02
78	148,500	1,988916E-02	3,708674E-03	2,023198E-02	-29,84	2,451551E-02
79	149,000	1,783271E-02	2,588865E-02	3,143609E-02	-26,01	2,550374E-02
80	149,500	3,516751E-04	1,047293E-03	1,104762E-03	-55,09	2,550496E-02
81	150,000	1,876804E-02	-1,292786E-02	2,278966E-02	-28,80	2,602433E-02
82	150,500	1,300252E-02	2,289796E-03	1,320261E-02	-33,54	2,619863E-02
83	151,000	-5,254642E-03	-7,628434E-03	9,263059E-03	-36,62	2,628444E-02
84	151,500	2,696746E-03	-1,301067E-02	1,328721E-02	-33,49	2,646099E-02
85	152,000	5,049954E-04	-3,485414E-04	6,144204E-04	-60,19	2,646137E-02
86	152,500	-7,418473E-03	-1,472395E-03	7,563180E-03	-38,38	2,651857E-02
87	153,000	-2,378151E-03	-3,452484E-03	4,192284E-03	-43,51	2,653614E-02
88	153,500	-2,395924E-04	2,467200E-03	2,478806E-03	-48,07	2,654229E-02
89	154,000	-2,949755E-03	2,031860E-03	3,581831E-03	-44,88	2,655512E-02
90	154,500	-9,441200E-05	-7,989418E-05	1,236799E-04	-74,11	2,655513E-02

S-BAND SPECTRUM RUN NUMBER PRO 1

LINE NO.	FREQUENCY, KILOHERTZ	COMPLEX COEFFICIENTS REAL	COMPLEX COEFFICIENTS IMAGINARY	AMPLITUDE COEFFICIENT	DECIBELS REL TO MAX	CUMMULATIVE POWER
91	155,000	1,020103D-03	1.480936D-03	1,798272D-03	-50,86	2,655837D-02
92	155.500	-2,507581D-05	9,466242D-04	9,469562D-04	-56,43	2,655928D-02
93	156,000	3,915518D-04	-2,697099D-04	4,754537D-04	-62,42	2,655949D-02
94	156,500	8,276955D-04	1,140890D-04	8,355215D-04	-57,52	2,656019D-02
95	157,000	4,955311D-05	7,194605D-05	8,736270D-05	-77,13	2,656019D-02
96	157,500	1,631060D-04	-3.120909D-04	3,521425D-04	-65,02	2,656032D-02
97	158,000	1,464567D-04	-1,008828D-04	1,778395D-04	-70,96	2,656035D-02
98	158,500	2,846989D-05	-2,032487D-05	3,498050D-05	-85,08	2,656035D-02
99	159,000	-6,231368D-05	-9,046397D-05	1,098486D-04	-75,14	2,656036D-02
100	159.500	8,193145D-05	-2,554384D-05	8,582104D-05	-77,29	2,656037D-02
101	160,000	-3,337917D-05	2.299235D-05	4,053168D-05	-83,80	2,656037D-02
102	160,500	4,234224D-05	-1,003053D-05	4,351410D-05	-83,19	2,656037D-02
103	161,000	3,610607D-06	5,241703D-06	6,364898D-06	-99,88	2,656037D-02
104	161,500	5,638647D-05	9,204238D-06	5,713276D-05	-80,82	2,656038D-02
105	162,000	-2,590859D-06	1,784643D-06	3,146029D-06	-106,00	2,656038D-02
106	162,500	5,570161D-05	-2,627346D-06	5,576354D-05	-81,03	2,656038D-02
107	163,000	1,755345D-06	2,548325D-06	3,094382D-06	-106,15	2,656038D-02
108	163.500	4,530676D-05	-3,191270D-06	4,541901D-05	-82,81	2,656038D-02
109	164,000	1,161985D-06	-8,004020D-07	1,410976D-06	-112,97	2,656038D-02
110	164.500	4,036111D-05	-2,173400D-06	4,041958D-05	-83,83	2,656038D-02
111	165,000	-2,136128D-07	-3,101126D-07	3,765638D-07	-124,44	2,656038D-02
112	165,500	3,552570D-05	-2,152847D-06	3,559087D-05	-84,93	2,656039D-02
113	166,000	-1,241879D-08	8,554351D-09	1,507990D-08	-152,39	2,656039D-02
114	166,500	3,150498D-05	-1,549437D-06	3,154306D-05	-85,98	2,656039D-02
115	167,000	-2,498385D-08	-3,627034D-08	4,404237D-08	-143,08	2,656039D-02
116	167,500	2,831017D-05	-1,245027D-06	2,833753D-05	-86,91	2,656039D-02
117	168,000	-2,206528D-08	1,519907D-08	2,679344D-08	-147,40	2,656039D-02
118	168,500	2,544801D-05	-1,065636D-06	2,547031D-05	-87,84	2,656039D-02
119	169,000	5,154415D-09	7,482929D-09	9,086375D-09	-156,79	2,656039D-02
120	169,500	2,295488D-05	-8,940692D-07	2,297229D-05	-88,73	2,656039D-02
121	170,000	1,310331D-09	-9,025866D-10	1,591110D-09	-171,92	2,656039D-02

C. Computer program listing for obtaining the S-band spectrum when the range code modulates the transmitter.

Listing of the ALGOL program for computing the spectrum out of the S-band transmitter when only the range data is modulating the transmitter. The form of the output (not shown) is identical to that shown in Appendix D.

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```
% S-BAND SPECTRUM FOR RANGE DATA ONLY.
BEGIN    INTEGER I,LIM,N; %
         INTEGER LNS; %
         LIM ← 4000;    N ← 7;
         LNS ← N × LIM / 500 + 20; %
         IF LNS > 1000 THEN %
   BEGIN LNS ← 1000; LIM ← 490000 / N;   END; %
BEGIN %
         REAL PI,BETA;
         LABEL EXIT;
         REAL ARRAY R0[0:2,0:LNS]; %
         REAL ARRAY A1[0:2,0:LNS]; %
         REAL ARRAY A2[0:2,0:LNS]; %
         SAVE ARRAY ARF[0:2,0:LNS]; %
         INTEGER ARRAY IMU[0:100]; %
         FILE OUT PRT 6(2,15); %
%    ****************************************************************
         REAL     PROCEDURE FACTORIAL(N);                                    F 1
         VALUE N; INTEGER N ; BEGIN INTEGER I;
         REAL F ;  F ← 1.0 ;                                                 F 2 1
         FOR I ← 2 STEP 1 UNTIL N DO F ← I × F; FACTORIAL ← F END ;          F 3
%    ****************************************************************
```

```
          PROCEDURE RANGEDATA(LO,HI,N,I); %
          VALUE LO,HI,N; INTEGER N; REAL LO,HI; INTEGER ARRAY I[O];
    BEGIN INTEGER J,K,L,N1,N2; %
          REAL ANG,PIN,NPIN,CO1,CO2; %
          LABEL L1,L2; %
          N1 ← (N×LO)/ 996;    N2 ← (N×HI)/ 996; K ← 0; PIN ← PI/N; %
          FOR J ← N1 STEP 1 UNTIL N2 DO %
    BEGIN CO1 ← CO2 ← 0.0; NPIN ← J×PIN; %
          IF J MOD N = 0 THEN %
    BEGIN IF J = 0 THEN %
      BEGIN ANG ← 1/N; GO TO L1; END; %
          GO TO L2; %
    END; %
          ANG ← SIN(J×PIN) / (J×PI); %
L1:       K ← K+1; %
          FOR L ← 0 STEP 1 UNTIL (N-1) DO %
    BEGIN CO1 ← CO1 + I[L]×COS((2×L-1)×NPIN); %
          CO2 ← CO2 - I[L]×SIN((2×L-1)×NPIN); %
    END; %
          RD[O,K] ← J × 996/N; %
          RD[1,K] ← CO1 × ANG; %
          RD[2,K] ← CO2 × ANG; %
L2: END; %
          RD[1,O] ← K; %
    END RANGEDATA; %
%   ******************************************************************
          PROCEDURE SUM(A,B);    ARRAY A,B[O,O];
BEGIN     INTEGER I,K,L,ASTOP,BMAX;
          ASTOP ← A[1,O]; BMAX ← B[1,O]; K ← B[O,O]; %
          FOR I ← BMAX +1 STEP 1 UNTIL K DO
BEGIN     B[O,I] ← 999999999.0; B[1,I] ← B[2,I] ← 0.0 ;          END;
          K ← 1 ; FOR I ← 1 STEP 1 UNTIL ASTOP DO
BEGIN     WHILE A[O,I] > B[O,K] + @-6 DO K ← K+1;
          IF ABS(A[O,I] - B[O,K]) < @-6 THEN
BEGIN     B[1,K] ← B[1,K] + A[1,I]; B[2,K] ← B[2,K] + A[2,I]    END
ELSE BEGIN FOR L ← BMAX STEP -1 UNTIL K DO
BEGIN     B[O,L+1] ← B[O,L]; B[1,L+1] ← B[1,L]; B[2,L+1] ← B[2,L] END;
          BMAX ← BMAX+1; B[O,K] ← A[O,I]; B[1,K]←A[1,I]; B[2,K]←A[2,I];
END; END; B[1,O] ← BMAX ;
END SUM; %
%   ******************************************************************
```

```
%  THE FOLLOWING PROCEDURE IS DESIGNED TO ADD TO THE SUM ARRAY A1 THE
%  PRODUCT OF   (J*N × BETA*N)/FACT(N) TIMES THE SPECTRAL ARRAY A2.
   PROCEDURE COMBINE(A1,A2,N);
   VALUE N; INTEGER N;  ARRAY A1,A2[0,0];
BEGIN
         INTEGER LIM,I;
         REAL COEF;
         SAVE ARRAY C[0:2,0:LNS]; %
         COEF ← BETA*N / FACTORIAL(N);
         N ← N MOD 4;
         IF N DIV 2 > 0 THEN COEF ← -COEF;
         N ← N MOD 2;
         C[0,0] ← A2[0,0];
         LIM ← C[1,0] ← A2[1,0];
         IF N = 0 THEN
   BEGIN
         FOR I ← 1 STEP 1 UNTIL LIM DO
     BEGIN
         C[0,I] ← A2[0,I];
         C[1,I] ← COEF × A2[1,I];
         C[2,I] ← COEF × A2[2,I];
     END;
   END
 ELSE
   BEGIN
         FOR I ← 1 STEP 1 UNTIL LIM DO
     BEGIN
         C[0,I] ← A2[0,I];
         C[1,I] ← -COEF × A2[2,I];
         C[2,I] ←  COEF × A2[1,I];
     END;
   END;
         SUM(C,A1);
END COMBINE;
%   ********************************************************************
```

```
         PROCEDURE PRINT(A);  ARRAY A[0,0]; %                                   P 1
BEGIN    INTEGER I,J,K,PAGE; %                                                  P 2
         REAL SUMP,X,Y,Z,F,DB; %                                                P 3
         FORMAT PTITLE(X35,"ARRAY SIZE: ",I4," LINES; LINES FILLED: ",          P 4
                       I4,X34,"PAGE ",I2/" LINE",X6,"FREQ",X12,"REAL",          P 5
                       X13,"IMAG",X10,"AMPLITUDE",X8,"DB",X7,                   P 6
                       "SUM OF POWER",X6,"FREQ"/),                              P 7
              FMTM(I4,X2,F11.4,3(X2,F15.8),X3,F7.2,X2,F15.8,X2,F11.4);         P 8
         LIST LSTM(I,F,X,Y,SQRT(Z),DB,SUMP,F); %                                P 9
         J ← A[0,0]; K ← A[1,0]; SUMP ← 0; PAGE ← 1; %                          P10
         WRITE(PRT,PTITLE,J,K,PAGE); %                                          P11
         FOR I ← 1 STEP 1 UNTIL K DO %                                          P12
   BEGIN %                                                                      P13
         F ← A[0,I]; X ← A[1,I]; Y ← A[2,I]; %                                  P14
         Z ← X×X  + Y×Y; SUMP ← SUMP + Z; %                                     P15
         DB ← IF ABS(Z) > @-30 THEN 4.342944819×LN(Z) ELSE @20; %               P16
         WRITE(PRT,FMTM,LSTM); %                                                P17
         IF I MOD 5 = 0 THEN %                                                  P18
    BEGIN IF I MOD 45 = 0 THEN %                                                P19
     BEGIN WRITE(PRT[PAGE]); PAGE←PAGE+1; WRITE(PRT,PTITLE,J,K,PAGE);           P20
     END ELSE WRITE(PRT); END; %                                                P21
   END; %                                                                       P22
         WRITE(PRT[PAGE]);
END PRINT; %                                                                    P23
%    ******************************************************************
PROCEDURE PRINTIME; BEGIN FORMAT FMTT(/"PROCESSOR TIME",F9.3," SECONDS",        PT1
X10,"IO TIME",F9.3," SECONDS"/); LIST LSTT(TIME(2   ,0,TIME(3)/60));           PT2
WRITE(    PRT,FMTT,LSTT); END PRINTIME; %                                       PT3
%    ******************************************************************
```

```
          PROCEDURE CONVOLVE(A,B,C,F);                                    C 1
          VALUE F; REAL F;                  ARRAY A,B,C[0,0];              C 1 1
BEGIN     INTEGER I,J,K,L,ASTOP,BSTOP,CMAX,CSTOP,ILO,IHI,JLO,JHI;          C 2
          REAL FRQ,RE,IM,FA,RA,IA,RB,IB,FFF;                               C 2 1
          BOOLEAN SKIP1;                                                   C 2 2
          LABEL L1;                                                        C 2 3
          CSTOP ← C[0,0] - 1.0 ;                                           C 2 2
          FOR I ← 1 STEP 1 UNTIL CSTOP + 1 DO                              C 3
          C[0,I] ← 999999999.0;                                            C 4
          CMAX ← 0; ASTOP ← A[1,0]; BSTOP ← B[1,0];                        C 5
          EFF ← -B[0,BSTOP] - F - 1@-6; ILO ← 1;                           C 5 1
          WHILE A[0,ILO] < EFF DO ILO ← ILO+1;                             C 5 2
          EFF ← -B[0,1] + F + 1@-6; IHI ← ASTOP;                           C 5 3
          WHILE A[0,IHI] > EFF DO IHI ← IHI - 1; SKIP1 ← FALSE;            C 5 4
          FOR I ← ILO STEP 1 UNTIL IHI DO                                  C 6
BEGIN     FA ← A[0,I] ; RA ← A[1,I] ; IA ← A[2,I] ; K ← 1 ;                C 6 1
          IF SKIP1 THEN GO TO L1;                                          C 6 2
          EFF ← -F - FA - 1@-6; JLO ← 1;                                   C 6 3
          WHILE B[0,JLO] < EFF DO JLO ← JLO + 1;                           C 6 4
          IF JLO = 1 THEN SKIP1 ← TRUE;                                    C 6 5
L1:       EFF ← F - FA + 1@-6; JHI ← BSTOP;                                C 7
          WHILE B[0,JHI] > EFF DO JHI ← JHI - 1;                           C 7 1
          FOR J ← JLO STEP 1 UNTIL JHI DO                                  C 7 2
BEGIN     RB ← B[1,J] ; IB ← B[2,J] ;                                      C 8
          FRQ ← FA + B[0,J] ;                                              C 8 1
          RE ← RA × RB - IA × IB ;                                         C 9
          IM ← RA × IB + IA × RB ;                                         C10
          WHILE FRQ > C[0,K] + 1.0@-6 DO K ← K + 1 ;                       C11
          IF ABS(FRQ - C[0,K]) < 1.0@-6 THEN                               C12
BEGIN     C[1,K] ← C[1,K] + RE;  C[2,K] ← C[2,K] + IM;          END        C13
ELSE BEGIN FOR L ← CMAX STEP -1 UNTIL K DO                                 C14
BEGIN     C[0,L+1] ← C[0,L];  C[1,L+1] ← C[1,L];  C[2,L+1] ← C[2,L] END;   C15
          CMAX ← CMAX + 1; C[0,K] ← FRQ; C[1,K] ← RE; C[2,K] ← IM;         C16
          IF CMAX > CSTOP      THEN
BEGIN     C[1,0] ← CMAX ;
          PRINT(C); GO TO EXIT  END ;
END; END; END;                                                             C17
          C[1,0] ← CMAX ;
END CONVOLVE;
%    ******************************************************************
```

```
            WRITE(PRT[NO]); %
            BETA ← 0.6;
            RD[0,0] ←A1[0,0] ← A2[0,0] ← ARF[0,0] ← LNS; %
            ARF[1,0]←ARF[1,1]←1;    ARF[0,1]←ARF[2,1]←0;
            PI ← 3.1415926541;
            FILL TMU[*] WITH -1,1,-1,1,1,1,-1;
            RANGEDATA(-LIM,LIM,N,TMU); %
            PRINT(RD); %
            COMBINE(ARF,RD,1);
            PRINT(ARF);
            PRINTIME; WRITE(PRT[PAGE]); %
            CONVOLVE(RD,RD,A1,LIM); %
            PRINT(A1);
            COMBINE(ARF,A1,2);
            PRINT(ARF);
            PRINTIME; WRITE(PRT[PAGE]); %
            CONVOLVE(RD,A1,A2,LIM); %
            PRINT(A2);
            COMBINE(ARF,A2,3);
            PRINT(ARF);
            PRINTIME; WRITE(PRT[PAGE]); %
            CONVOLVE(A1,A1,A2,LIM); %
            PRINT(A2);
            COMBINE(ARF,A2,4);
            PRINT(ARF);
    EXIT:
            PRINTIME; WRITE(PRT[PAGE]); %
    END; %
    END.
```

D. Computer program listing and sample calculation for the S-band spectrum when the transmitter is modulated by the command data subcarrier and range code simultaneously.

Listing of the ALGOL program for computing the spectrum out of the S-band transmitter when both the range data and the unmodulated 70 kHz subcarrier are present. The attached sample output was run for a 15 bit PN range data code, the command data modulation index (β_1) was 1.22 radians, and the range code index (β_2) was 0.6 radian.

```
%
% S-BAND SPECTRUM FOR RANGE DATA PLUS 70 KHZ SUBCARRIER.
%
BEGIN    INTEGER I,LIM,N; %
         INTEGER LNS; %
         LIM ← 4000;  N ← 15;
         LNS ← N × LIM / 500 + 20; %
         IF LNS > 1000 THEN %
   BEGIN LNS ← 1000; LIM ← 490000 / N;  END; %
BEGIN %
         REAL PI,BETA;
         REAL BETA1;
         LABEL EXIT;
         ARRAY CD[0:2,0:351];
         REAL ARRAY RD[0:2,0:LNS]; %
         REAL ARRAY A1[0:2,0:LNS]; %
         REAL ARRAY A2[0:2,0:900]; %
         SAVE ARRAY ARF[0:2,0:LNS]; %
         INTEGER ARRAY TMU[0:100]; %
         FILE OUT PRT 6(2,15); %
% ***********************************************************************
         REAL    PROCEDURE FACTORIAL(N);
         VALUE N; INTEGER N ; BEGIN INTEGER I;
         REAL F ;  F ← 1.0 ;                                                    F 2 1
         FOR I ← 2 STEP 1 UNTIL N DO F ← I × F; FACTORIAL ← F END ;             F 3
% ***********************************************************************
         REAL PROCEDURE JAY(N,X);                                               J 1
         VALUE N,X ; INTEGER N ; REAL X ; BEGIN INTEGER   P,NPOS; REAL          J 2
         XSQ,    A,SUMA,F; LABEL RPT; NPOS←ABS(N); A←SUMA←P←1; XSQ←X×X;         J 3
    RPT: A ← - (XSQ × A)/(4.0 × P × (NPOS +P)); SUMA ← SUMA + A; P←P+1;         J 4
         IF ABS(A) > 1.0@-7 THEN GO TO RPT;                                     J 5
         F ← (((SIGN(N)×X/2.0)*NPOS)×SUMA)/FACTORIAL(NPOS); JAY←F  END;         J 6
% ***********************************************************************
```

```
            PROCEDURE RANGEDATA(LO,HI,N,I); %
            VALUE LO,HI,N; INTEGER N; REAL LO,HI; INTEGER ARRAY I[0];
     BEGIN  INTEGER J,K,L,N1,N2; %
            REAL ANG,PIN,NPIN,CO1,CO2; %
            LABEL L1,L2; %
            N1 ← (N×LO)/ 996;   N2 ← (N×HI)/ 996; K ← 0; PIN ← PI/N; %
            FOR J ← N1 STEP 1 UNTIL N2 DO %
     BEGIN  CO1 ← CO2 ← 0.0; NPIN ← J×PIN; %
            IF J MOD N = 0 THEN %
     BEGIN  IF J = 0 THEN %
       BEGIN ANG ← 1/N; GO TO L1; END; %
            GO TO L2; %
     END; %
            ANG ← SIN(J×PIN) / (J×PI); %
L1:         K ← K+1; %
            FOR L ← 0 STEP 1 UNTIL (N-1) DO %
     BEGIN  CO1 ← CO1 + I[L]×COS((2×L-1)×NPIN); %
            CO2 ← CO2 - I[L]×SIN((2×L-1)×NPIN); %
     END; %
            RD[0,K] ← J × 996/N; %
            RD[1,K] ← CO1 × ANG; %
            RD[2,K] ← CO2 × ANG; %
L2: END; %
            RD[1,0] ← K; %
     END RANGEDATA; %
% ****************************************************************************
            PROCEDURE SUM(A,B);    ARRAY A,B[0,0];
BEGIN       INTEGER I,K,L,ASTOP,BMAX;
            ASTOP ← A[1,0]; BMAX ← B[1,0]; K ← B[0,0]; %
            FOR I ← BMAX +1 STEP 1 UNTIL K DO
BEGIN       B[0,I] ← 999999999.0; B[1,I] ← B[2,I] ← 0.0 ;            END;
            K ← 1 ; FOR I ← 1 STEP 1 UNTIL ASTOP DO
BEGIN       WHILE A[0,I] > B[0,K] + @-6 DO K ← K+1;
            IF ABS(A[0,I] - B[0,K]) < @-6 THEN
BEGIN       B[1,K] ← B[1,K] + A[1,I]; B[2,K] ← B[2,K] + A[2,I]     END
ELSE BEGIN FOR L ← BMAX STEP -1 UNTIL K DO
BEGIN       B[0,L+1] ← B[0,L]; B[1,L+1] ← B[1,L]; B[2,L+1] ← B[2,L] END;
            BMAX ← BMAX+1; B[0,K] ← A[0,I]; B[1,K]←A[1,I]; B[2,K]←A[2,I];
END; END; B[1,0] ← BMAX ;
END SUM; %
% ****************************************************************************
```

```
%  THE FOLLOWING PROCEDURE IS DESIGNED TO ADD TO THE SUM ARRAY A1 THE
%  PRODUCT OF    (J*N × BETA*N)/FACT(N) TIMES THE SPECTRAL ARRAY A2.
  PROCEDURE COMBINE(A1,A2,N);
  VALUE N; INTEGER N;  ARRAY A1,A2[0,0];
BEGIN
        INTEGER LIM,I;
        REAL COEF;
        SAVE ARRAY C[0:2,0:LNS1]; %
        COEF ← BETA*N / FACTORIAL(N);
        N ← N MOD 4;
        IF N DIV 2 > 0 THEN COEF ← -COEF;
        N ← N MOD 2;
        C[0,0] ← A2[0,0];
        LIM ← C[1,0] ← A2[1,0];
        IF N = 0 THEN
  BEGIN
        FOR I ← 1 STEP 1 UNTIL LIM DO
    BEGIN
        C[0,I] ← A2[0,I];
        C[1,I] ← COEF × A2[1,I];
        C[2,I] ← COEF × A2[2,I];
    END;
  END
 ELSE
  BEGIN
        FOR I ← 1 STEP 1 UNTIL LIM DO
    BEGIN
        C[0,I] ← A2[0,I];
        C[1,I] ← -COEF × A2[2,I];
        C[2,I] ←  COEF × A2[1,I];
    END;
  END;
        SUM(C,A1);
END COMBINE;
% ******************************************************************
```

```
          PROCEDURE PRINT(A);  ARRAY A[0,0]; %
BEGIN     INTEGER I,J,K,PAGE; %
          REAL SUMP,X,Y,Z,F,DB; %
          FORMAT PTITLE(X35,"ARRAY SIZE: ",I4," LINES; LINES FILLED: ",
                        I4,X34,"PAGE ",I2/" LINE",X6,"FREQ",X12,"REAL",
                        X13,"IMAG",X10,"AMPLITUDE",X8,"DB",X7,
                        "SUM OF POWER",X6,"FREQ"/),
                 FMTM(I4,X2,F11.4,3(X2,F15.8),X3,F7.2,X2,F15.8,X2,F11.4);
          LIST LSTM(I,F,X,Y,SQRT(Z),DB,SUMP,F); %
          J ← A[0,0]; K ← A[1,0]; SUMP ← 0; PAGE ← 1; %
          WRITE(PRT,PTITLE,J,K,PAGE); %
          FOR I ← 1 STEP 1 UNTIL K DO %
   BEGIN %
          F ← A[0,I]; X ← A[1,I]; Y ← A[2,I]; %
          Z ← X×X  + Y×Y; SUMP ← SUMP + Z; %
          DB ← IF ABS(Z) > @-30 THEN 4.342944819×LN(Z) ELSE @20; %
          WRITE(PRT,FMTM,LSTM); %
          IF I MOD 5 = 0 THEN %
    BEGIN IF I MOD 45 = 0 THEN %
     BEGIN WRITE(PRT[PAGE]); PAGE←PAGE+1; WRITE(PRT,PTITLE,J,K,PAG );
     END ELSE WRITE(PRT); END; %
   END; %
          WRITE(PRT[PAGE]);
END PRINT; %
% ************************************************************************
PROCEDURE PRINTIME; BEGIN FORMAT FMTT(/"PROCESSOR TIME",F9.3," SECONDS",
X10,"IO TIME",F9.3," SECONDS"/); LIST LSTT(TIME(2)/60,TIME(3)/60);
WRITE(    PRT,FMTT,LSTT); END PRINTIME; %
% ************************************************************************
```

```
        PROCEDURE CONVOLVE(A,B,C,F);                                   C 1
        VALUE F; REAL F;                   ARRAY A,B,C[0,0];           C 1 1
REGIN   INTEGER I,J,K,L,ASTOP,BSTOP,CMAX,CSTOP,ILO,IHI,JLO,JHI;        C 2
        REAL FRQ,RE,IM,FA,RA,IA,RB,IB,EFF;                             C 2 1
        BOOLEAN SKIP1;                                                 C 2 2
        LABEL L1;                                                      C 2 3
        CSTOP ← C[0,0] - 1.0 ;                                         C 2 2
        FOR I ← 1 STEP 1 UNTIL CSTOP + 1 DO                            C 3
        C[0,I] ← 99999999.0;                                           C 4
        CMAX ← 0; ASTOP ← A[1,0]; BSTOP ← B[1,0];                      C 5
        EFF ← -B[0,BSTOP] - F - 1@-6; ILO ← 1;                         C 5 1
        WHILE A[0,ILO] < EFF DO ILO ← ILO+1;                           C 5 2
        EFF ← -B[0,1] + F + 1@-6; IHI ← ASTOP;                         C 5 3
        WHILE A[0,IHI] > EFF DO IHI ← IHI - 1; SKIP1 ← FALSE;          C 5 4
        FOR I ← ILO STEP 1 UNTIL IHI DO                                C 6
REGIN   FA ← A[0,I] ; RA ← A[1,I] ; IA ← A[2,I] ; K ← 1 ;              C 6 1
        IF SKIP1 THEN GO TO L1;                                        C 6 2
        EFF ← -F - FA - 1@-6; JLO ← 1;                                 C 6 3
        WHILE B[0,JLO] < EFF DO JLO ← JLO + 1;                         C 6 4
        IF JLO = 1 THEN SKIP1 ← TRUE;                                  C 6 5
L1;     EFF ← F - FA + 1@-6; JHI ← BSTOP;                              C 7
        WHILE B[0,JHI] > EFF DO JHI ← JHI - 1;                         C 7 1
        FOR J ← JLO STEP 1 UNTIL JHI DO                                C 7 2
REGIN   RB ← B[1,J] ; IB ← B[2,J] ;                                    C 8
        FRQ ← FA + B[0,J] ;                                            C 8 1
        RE ← RA × RB - IA × IB ;                                       C 9
        IM ← RA × IB + IA × RB ;                                       C10
        WHILE FRQ > C[0,K] + 1.0@-6 DO K ← K + 1 ;                     C11
        IF ABS(FRQ - C[0,K]) < 1.0@-6 THEN                             C12
REGIN   C[1,K] ← C[1,K] + RE;  C[2,K] ← C[2,K] + IM;           END     C13
FLSE REGIN FOR L ← CMAX STEP -1 UNTIL K DO                             C14
REGIN   C[0,L+1] ← C[0,L];  C[1,L+1] ← C[1,L];  C[2,L+1] ← C[2,L] END; C15
        CMAX ← CMAX + 1; C[0,K] ← FRQ; C[1,K] ← RE; C[2,K] ← IM;       C16
        IF CMAX > CSTOP      THEN
REGIN   C[1,0] ← CMAX ;
        PRINT(C); GO TO EXIT  END ;
END; END; END;                                                         C17
        C[1,0] ← CMAX ;
END CONVOLVE;
% ************************************************************************
```

```
          WRITE(PRT[NO]); %
          BETA ← 0.6;
          RD[0,0] ←A1[0,0] ←            ARF[0,0] ← LNS; %
          A2[0,0] ← 900; %
          ARF[1,0]←ARF[1,1]←1;    ARF[0,1]←ARF[2,1]←0;
          PI ← 3.1415926540;
          FOR I ← 0 STEP 1 UNTIL 99 DO IMU[I] ← 0; %
          FILL IMU[*] WITH -1,-1,-1,1,-1,-1,1,1,-1,1,-1,1,1,1,1;
BEGIN
          INTEGER I,J;
          BETA1 ← 1.22;
          I ← 0; CD[0,0] ← 35;
          FOR J ← -5 STEP 1 UNTIL 5 DO
BEGIN
          I ← I + 1;
         CD[0,I] ← J × 70;
         CD[1,I] ← JAY(J,BETA1) × COS(J×PI/2);
         CD[2,I] ← JAY(J,BETA1) × SIN(J × PI/2);
END;
         CD[1,0] ← I;
END;
          PRINT(CD);
          RANGEDATA(-LIM,LIM,N,IMU); %
          PRINT(RD); %
          COMBINE(ARF,RD,1);
          CONVOLVE(RD,RD,A1,LIM); %
          COMBINE(ARF,A1,2);
          CONVOLVE(RD,A1,A2,LIM); %
          COMBINE(ARF,A2,3);
          CONVOLVE(A1,A1,A2,LIM); %
          COMBINE(ARF,A2,4);
          PRINT(ARF);
          CONVOLVE(ARF,CD,A2,2000); %
          PRINT(A2);
EXIT:
          PRINTIME;
END; %
END.
```

ARRAY SIZE: 900 LINES; LINES FILLED: 665

LINE	FREQ	REAL	IMAG	AMPLITUDE	DB	SUM OF POWER	FREQ
1	-1999.2000	-0.00144300	-0.00082463	0.00166201	-55.59	0.00000276	-1999.2000
2	-1995.6000	-0.00084462	0.00152923	0.00174698	-55.15	0.00000581	-1995.6000
3	-1992.0000	0.00423868	0.00000653	0.00423869	-47.46	0.00002378	-1992.0000
4	-1988.4000	0.00080506	0.00141896	0.00163143	-55.75	0.00002644	-1988.4000
5	-1984.8000	-0.00128040	0.00068772	0.00145340	-56.75	0.00002855	-1984.8000
6	-1981.2000	-0.00040551	0.00027290	0.00048879	-66.22	0.00002879	-1981.2000
7	-1977.6000	0.00003303	-0.00008076	0.00008725	-81.18	0.00002880	-1977.6000
8	-1974.0000	-0.00000482	0.00000945	0.00001061	-99.48	0.00002880	-1974.0000
9	-1943.6000	-0.00000638	-0.00001695	0.00001811	-94.84	0.00002880	-1943.6000
10	-1940.0000	0.00011081	-0.00005918	0.00012562	-78.02	0.00002882	-1940.0000
11	-1936.4000	0.00066452	-0.00029029	0.00072516	-62.79	0.00002934	-1936.4000
12	-1932.8000	0.00157685	-0.00230818	0.00279538	-51.07	0.00003716	-1932.8000
13	-1929.2000	-0.00253055	0.00442817	0.00510023	-45.85	0.00006317	-1929.2000
14	-1925.6000	0.00200861	0.00110939	0.00229461	-52.79	0.00006844	-1925.6000
15	-1922.0000	-0.00000497	0.00322707	0.00322708	-49.82	0.00007885	-1922.0000
16	-1918.4000	-0.00046239	0.00026234	0.00053163	-65.49	0.00007913	-1918.4000
17	-1914.8000	-0.00014440	-0.00026884	0.00030517	-70.31	0.00007922	-1914.8000
18	-1911.2000	-0.00004242	-0.00006303	0.00007597	-82.39	0.00007923	-1911.2000
19	-1907.6000	0.00000998	0.00000408	0.00001078	-99.35	0.00007923	-1907.6000
20	-1877.2000	0.00001961	-0.00000803	0.00002119	-93.48	0.00007923	-1877.2000
21	-1873.6000	-0.00013716	0.00005167	0.00014657	-76.68	0.00007925	-1873.6000
22	-1870.0000	-0.00038074	-0.00071290	0.00080820	-61.85	0.00007991	-1870.0000
23	-1866.4000	-0.00138254	-0.00316486	0.00345366	-49.23	0.00009183	-1866.4000
24	-1862.8000	-0.00708317	-0.00483890	0.00857824	-41.33	0.00016542	-1862.8000
25	-1859.2000	0.00581630	0.00332381	0.00669903	-43.48	0.00021030	-1859.2000
26	-1855.6000	-0.00084462	0.00152923	0.00174698	-55.15	0.00021335	-1855.6000
27	-1852.0000	-0.00105160	-0.00000162	0.00105160	-59.56	0.00021445	-1852.0000
28	-1848.4000	-0.00005508	-0.00009709	0.00011163	-79.04	0.00021447	-1848.4000
29	-1844.8000	0.00004179	-0.00002244	0.00004743	-86.48	0.00021447	-1844.8000
30	-1841.2000	0.00060779	-0.00000524	0.00000939	-100.55	0.00021447	-1841.2000
31	-1810.8000	-0.00002040	-0.00000829	0.00002202	-93.14	0.00021447	-1810.8000
32	-1807.2000	-0.00006497	-0.00015871	0.00017149	-75.32	0.00021450	-1807.2000
33	-1803.6000	0.00033244	0.00088247	0.00094301	-60.51	0.00021539	-1803.6000
34	-1800.0000	-0.00339527	0.00181332	0.00384915	-48.29	0.00023020	-1800.0000
35	-1796.4000	-0.00971207	0.00424261	0.01059830	-39.50	0.00034253	-1796.4000
36	-1792.8000	-0.00635577	0.00930357	0.01126731	-38.96	0.00046948	-1792.8000
37	-1789.2000	-0.00253055	0.00442817	0.00510023	-45.85	0.00049549	-1789.2000
38	-1785.6000	-0.00049833	-0.00027524	0.00056929	-64.89	0.00049582	-1785.6000
39	-1782.0000	0.00000034	-0.00022080	0.00022080	-73.12	0.00049587	-1782.0000
40	-1778.4000	0.00001509	-0.00000856	0.00001735	-95.21	0.00049587	-1778.4000
41	-1774.8000	0.00000277	0.00000516	0.00000586	-104.64	0.00049587	-1774.8000
42	-1744.4000	0.00000714	-0.00001961	0.00002087	-93.61	0.00049587	-1744.4000
43	-1740.8000	-0.00006713	0.00016509	0.00017822	-74.98	0.00049590	-1740.8000
44	-1737.2000	-0.00102111	0.00041800	0.00110335	-59.15	0.00049712	-1737.2000
45	-1733.6000	0.00420284	-0.00158330	0.00449118	-46.95	0.00051729	-1733.6000

ARRAY SIZE: 900 LINES; LINES FILLED: 665

LINE	FREQ	REAL	IMAG	AMPLITUDE	DB	SUM OF POWER	FREQ
46	-1730.0000	0.00556457	0.01041912	0.01181196	-38.55	0.00065681	-1730.0000
47	-1726.4000	0.00557257	0.01275656	0.01392061	-37.13	0.00085059	-1726.4000
48	-1722.8000	-0.00708317	-0.00483890	0.00857824	-41.33	0.00092418	-1722.8000
49	-1719.2000	-0.00144300	-0.00082463	0.00166201	-55.59	0.00092694	-1719.2000
50	-1715.6000	0.00005779	-0.00010463	0.00011953	-78.45	0.00092696	-1715.6000
51	-1712.0000	0.00003432	0.00000005	0.00003432	-89.29	0.00092696	-1712.0000
52	-1708.4000	0.00000106	0.00000186	0.00000214	-113.38	0.00092696	-1708.4000
53	-1678.0000	-0.00000941	0.00001721	0.00001961	-94.15	0.00092696	-1678.0000
54	-1674.4000	-0.00015872	-0.00005782	0.00016892	-75.45	0.00092699	-1674.4000
55	-1670.8000	0.00106217	0.00043190	0.00114662	-58.81	0.00092830	-1670.8000
56	-1667.2000	0.00199076	0.00486312	0.00525481	-45.59	0.00095591	-1667.2000
57	-1663.6000	-0.00485871	-0.01289733	0.01378217	-37.21	0.00114586	-1663.6000
58	-1660.0000	0.01368526	-0.00730892	0.01551472	-36.19	0.00138657	-1660.0000
59	-1656.4000	-0.00971207	0.00424261	0.01059830	-39.50	0.00149889	-1656.4000
60	-1652.8000	0.00157685	-0.00230818	0.00279538	-51.07	0.00150671	-1652.8000
61	-1649.2000	0.00017315	-0.00030299	0.00034897	-69.14	0.00150683	-1649.2000
62	-1645.6000	0.00001626	0.00000898	0.00001858	-94.62	0.00150683	-1645.6000
63	-1642.0000	-0.00000001	0.00000424	0.00000424	-107.45	0.00150683	-1642.0000
64	-1611.6000	0.00001710	0.00000798	0.00001887	-94.48	0.00150683	-1611.6000
65	-1608.0000	0.00013927	0.00007618	0.00015875	-75.99	0.00150685	-1608.0000
66	-1604.4000	-0.00037199	0.00102115	0.00108680	-59.28	0.00150803	-1604.4000
67	-1600.8000	0.00205698	-0.00505870	0.00546091	-45.25	0.00153786	-1600.8000
68	-1597.2000	0.01492356	-0.00610908	0.01612555	-35.85	0.00179789	-1597.2000
69	-1593.6000	-0.01694032	0.00638180	0.01810254	-34.85	0.00212559	-1593.6000
70	-1590.0000	0.00556457	0.01041912	0.01181196	-38.55	0.00226511	-1590.0000
71	-1586.4000	-0.00138254	-0.00316486	0.00345366	-49.23	0.00227704	-1586.4000
72	-1582.8000	0.00048465	0.00033109	0.00058694	-64.63	0.00227739	-1582.8000
73	-1579.2000	0.00004709	0.00002691	0.00005424	-85.31	0.00227739	-1579.2000
74	-1575.6000	-0.00000111	0.00000201	0.00000230	-112.78	0.00227739	-1575.6000
75	-1545.2000	0.00001333	-0.00000934	0.00001627	-95.77	0.00227739	-1545.2000
76	-1541.6000	0.00006462	-0.00013843	0.00015277	-76.32	0.00227741	-1541.6000
77	-1538.0000	0.00049013	-0.00089606	0.00102135	-59.82	0.00227846	-1538.0000
78	-1534.4000	0.00486335	0.00177166	0.00517600	-45.72	0.00230525	-1534.4000
79	-1530.8000	-0.01552372	-0.00631228	0.01675801	-35.52	0.00258608	-1530.8000
80	-1527.2000	-0.00802412	-0.01960172	0.02118051	-33.48	0.00303469	-1527.2000
81	-1523.6000	-0.00485871	-0.01289733	0.01378217	-37.21	0.00322464	-1523.6000
82	-1520.0000	-0.00339527	0.00181332	0.00384915	-48.29	0.00323946	-1520.0000
83	-1516.4000	0.00066452	-0.00029029	0.00072516	-62.79	0.00323998	-1516.4000
84	-1512.8000	-0.00005146	0.00007533	0.00009123	-80.80	0.00323999	-1512.8000
85	-1509.2000	-0.00000332	0.00000582	0.00000670	-103.48	0.00323999	-1509.2000
86	-1478.8000	0.00000624	0.00000926	0.00001117	-99.04	0.00323999	-1478.8000
87	-1475.2000	-0.00007559	-0.00010786	0.00013171	-77.61	0.00324001	-1475.2000
88	-1471.6000	-0.00089063	-0.00041574	0.00098289	-60.15	0.00324097	-1471.6000
89	-1468.0000	-0.00426759	-0.00233429	0.00486428	-46.26	0.00326463	-1468.0000
90	-1464.4000	0.00543672	-0.01492427	0.01588369	-35.98	0.00351693	-1464.4000

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LINE	FREQ	REAL	IMAG	AMPLITUDE	DB	SUM OF POWER	FREQ
91	-1460.8000	-0.00829102	0.02039003	0.02201123	-33.15	0.00400142	-1460.8000
92	-1457.2000	0.01492356	-0.00610908	0.01612555	-35.85	0.00426145	-1457.2000
93	-1453.6000	0.00420284	-0.00158330	0.00449118	-46.95	0.00428162	-1453.6000
94	-1450.0000	-0.00038074	-0.00071290	0.00080820	-61.85	0.00428228	-1450.0000
95	-1446.4000	0.00004512	0.00010329	0.00011271	-78.96	0.00428229	-1446.4000
96	-1442.8000	-0.00000931	-0.00000636	0.00001127	-98.96	0.00428229	-1442.8000
97	-1412.4000	0.00000245	0.00000470	0.00000530	-105.52	0.00428229	-1412.4000
98	-1408.8000	0.00007494	-0.00005052	0.00009037	-80.88	0.00428230	-1408.8000
99	-1405.2000	-0.00069397	0.00048631	0.00084740	-61.44	0.00428302	-1405.2000
100	-1401.6000	-0.00198002	0.00424174	0.00468111	-46.59	0.00430493	-1401.6000
101	-1398.0000	-0.00716329	0.01309603	0.01492711	-36.52	0.00452775	-1398.0000
102	-1394.4000	-0.01960266	-0.00714100	0.02086284	-33.61	0.00496301	-1394.4000
103	-1390.8000	-0.01552372	-0.00631228	0.01675801	-35.52	0.00524384	-1390.8000
104	-1387.2000	0.00199076	0.00486312	0.00525481	-45.59	0.00527145	-1387.2000
105	-1383.6000	0.00033244	0.00088947	0.00094301	-60.51	0.00527234	-1383.6000
106	-1380.0000	0.00011081	-0.00005918	0.00012562	-78.02	0.00527236	-1380.0000
107	-1376.4000	-0.00001276	0.00000557	0.00001392	-97.12	0.00527236	-1376.4000
108	-1346.0000	-0.00000001	0.00000356	0.00000356	-108.96	0.00527236	-1346.0000
109	-1342.4000	0.00003801	-0.00001983	0.00004287	-87.36	0.00527236	-1342.4000
110	-1338.8000	-0.00032503	-0.00048212	0.00058145	-64.71	0.00527270	-1338.8000
111	-1335.2000	0.00231608	0.00330512	0.00403584	-47.88	0.00528898	-1335.2000
112	-1331.6000	0.01301672	0.00607611	0.01436503	-34.85	0.00549534	-1331.6000
113	-1328.0000	0.01720131	0.00940881	0.01960640	-34.15	0.00587975	-1328.0000
114	-1324.4000	0.00543672	-0.01492427	0.01588369	-35.98	0.00613204	-1324.4000
115	-1320.8000	0.00205698	-0.00505870	0.00546091	-45.25	0.00616186	-132[illegible]8000
116	-1317.2000	-0.00102111	0.00041800	0.00110335	-59.15	0.00616308	-1317.2000
117	-1313.6000	-0.00013716	0.00005167	0.00014657	-76.68	0.00616310	-1313.6000
118	-1310.0000	0.00000731	0.00001369	0.00001552	-96.18	0.00616310	-1310.0000
119	-1279.6000	-0.00000280	0.00000544	0.00000611	-104.27	0.00616310	-1279.6000
120	-1276.0000	0.00002884	0.00000005	0.00002884	-90.80	0.00616310	-1276.0000
121	-1272.4000	-0.00012757	-0.00024453	0.00027581	-71.19	0.00616318	-1272.4000
122	-1268.8000	-0.00229617	0.00154799	0.00276923	-51.15	0.00617085	-1268.8000
123	-1265.2000	0.01014248	-0.00710740	0.01238487	-38.14	0.00632423	-1265.2000
124	-1261.6000	0.00798082	-0.01709714	0.01886811	-34.49	0.00668024	-1261.6000
125	-1258.0000	-0.00716329	0.01309603	0.01492711	-36.52	0.00690306	-1258.0000
126	-1254.4000	0.00486335	0.00177166	0.00517600	-45.72	0.00692985	-1254.4000
127	-1250.8000	0.00106217	0.00043190	0.00114662	-58.81	0.00693116	-1250.8000
128	-1247.2000	-0.00006497	-0.00015871	0.00017149	-75.32	0.00693119	-1247.2000
129	-1243.6000	-0.00000638	-0.00001695	0.00001811	-94.84	0.00693119	-1243.6000
130	-1213.2000	-0.00000843	0.00001199	0.00001465	-96.68	0.00693119	-1213.2000
131	-1209.6000	0.00004399	0.00002266	0.00004949	-86.11	0.00693119	-1209.6000
132	-1206.0000	0.00000031	-0.00018555	0.00018555	-74.63	0.00693123	-1206.0000
133	-1202.4000	-0.00116462	0.00060755	0.00131357	-57.63	0.00693295	-1202.4000
134	-1198.8000	0.00475033	0.00704630	0.00849800	-41.41	0.00700517	-1198.8000
135	-1195.2000	-0.00933539	-0.01332190	0.01626722	-35.77	0.00726979	-1195.2000

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LINE	FREQ	REAL	IMAG	AMPLITUDE	DB	SUM OF POWER	FREQ
136	-1191.6000	0.01301672	0.00607611	0.01436503	-34.85	0.00747615	-1191.6000
137	-1188.0000	-0.00426759	-0.00233429	0.00486428	-46.26	0.00749981	-1188.0000
138	-1184.4000	-0.00037199	0.00102115	0.00108680	-59.28	0.00750099	-1184.4000
139	-1180.8000	-0.00006713	0.00016509	0.00017822	-74.98	0.00750102	-1180.8000
140	-1177.2000	0.00001961	-0.00000803	0.00002119	-93.48	0.00750102	-1177.2000
141	-1146.8000	-0.00001962	-0.00001391	0.00002406	-92.38	0.00750102	-1146.8000
142	-1143.2000	0.00009703	0.00006823	0.00011862	-78.52	0.00750104	-1143.2000
143	-1139.6000	0.00014578	-0.00028305	0.00031839	-69.94	0.00750114	-1139.6000
144	-1136.0000	-0.00088369	-0.00000148	0.00088369	-61.07	0.00750192	-1136.0000
145	-1132.4000	0.00186440	0.00357389	0.00403097	-47.89	0.00751817	-1132.4000
146	-1128.8000	0.00925514	-0.00623944	0.01116192	-39.05	0.00764275	-1128.8000
147	-1125.2000	0.01014248	-0.00710740	0.01238487	-38.14	0.00779614	-1125.2000
148	-1121.6000	-0.00198002	0.00424174	0.00468111	-46.59	0.00781805	-1121.6000
149	-1118.0000	0.00049013	-0.00089606	0.00102135	-59.82	0.00781910	-1118.0000
150	-1114.4000	-0.00015872	-0.00005782	0.00016892	-75.45	0.00781912	-1114.4000
151	-1110.8000	-0.00002040	-0.00000829	0.00002202	-93.14	0.00781912	-1110.8000
152	-1080.4000	-0.00002907	0.00001424	0.00003237	-89.80	0.00781913	-1080.4000
153	-1076.8000	-0.00011263	0.00015884	0.00019472	-74.21	0.00781916	-1076.8000
154	-1073.2000	0.00043896	-0.00062427	0.00076315	-62.35	0.00781975	-1073.2000
155	-1069.6000	-0.00134806	-0.00069429	0.00151635	-56.38	0.00782205	-1069.6000
156	-1066.0000	-0.00000454	0.00271178	0.00271179	-51.33	0.00782940	-1066.0000
157	-1062.4000	0.00469422	-0.00244884	0.00529458	-45.52	0.00785743	-1062.4000
158	-1058.8000	0.00475033	0.00704630	0.00849800	-41.41	0.00792965	-1058.8000
159	-1055.2000	0.00231608	0.00330512	0.00403584	-47.88	0.00794594	-1055.2000
160	-1051.6000	-0.00089063	-0.00041574	0.00098289	-60.15	0.00794690	-1051.6000
161	-1048.0000	0.00013927	0.00007618	0.00015875	-75.99	0.00794693	-1048.0000
162	-1044.4000	0.00000714	-0.00001961	0.00002087	-93.61	0.00794693	-1044.4000
163	-1014.0000	0.00001979	0.00003515	0.00004033	-87.89	0.00794693	-1014.0000
164	-1010.4000	0.00011594	0.00023533	0.00026203	-71.63	0.00794700	-1010.4000
165	-1006.8000	0.00102193	0.00072463	0.00125277	-58.04	0.00794857	-1006.8000
166	-1003.2000	-0.00297317	-0.00209059	0.00363460	-48.79	0.00796178	-1003.2000
167	-999.6000	-0.00213058	0.00413683	0.00465325	-46.64	0.00798343	-999.6000
168	-996.0000	0.00356186	0.00000597	0.00356187	-48.97	0.00799612	-996.0000
169	-992.4000	0.00186440	0.00357389	0.00403097	-47.89	0.00801237	-992.4000
170	-988.8000	-0.00229617	0.00154799	0.00276923	-51.15	0.00802003	-988.8000
171	-985.2000	-0.00069397	0.00048631	0.00084740	-61.44	0.00802075	-985.2000
172	-981.6000	0.00006462	-0.00013843	0.00015277	-76.32	0.00802078	-981.6000
173	-978.0000	-0.00000941	0.00001721	0.00001961	-94.15	0.00802078	-978.0000
174	-947.6000	-0.00001600	-0.00004693	0.00004958	-86.09	0.00802078	-947.6000
175	-944.0000	0.00028450	-0.00016015	0.00032648	-69.72	0.00802089	-944.0000
176	-940.4000	0.00151405	-0.00074143	0.00168584	-55.46	0.00802373	-940.4000
177	-936.8000	0.00345111	-0.00486706	0.00596644	-44.49	0.00805933	-936.8000
178	-933.2000	-0.00641544	0.00912382	0.01115356	-39.05	0.00818373	-933.2000
179	-929.6000	0.00543363	0.00279846	0.00611193	-44.28	0.00822108	-929.6000
180	-926.0000	-0.00000454	0.00271178	0.00271179	-51.33	0.00822844	-926.0000

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LINE	FREQ	REAL	IMAG	AMPLITUDE	DB	SUM OF POWER	FREQ
181	-922.4000	-0.00116462	0.00060755	0.00131357	-57.63	0.00823016	-922.4000
182	-918.8000	-0.00032503	-0.00048212	0.00058145	-64.71	0.00823050	-918.8000
183	-915.2000	-0.00007559	-0.00010786	0.00013171	-77.61	0.00823052	-915.2000
184	-911.6000	0.00001710	0.00000798	0.00001887	-94.48	0.00823052	-911.6000
185	-881.2000	0.00005564	-0.00002139	0.00005961	-84.49	0.00823052	-881.2000
186	-877.6000	-0.00037986	0.00012949	0.00040132	-67.93	0.00823068	-877.6000
187	-874.0000	-0.00103039	-0.00183040	0.00210049	-53.55	0.00823510	-874.0000
188	-870.4000	-0.00353112	-0.00721084	0.00802901	-41.91	0.00829956	-870.4000
189	-866.8000	-0.01493565	-0.01059049	0.01830934	-34.75	0.00863479	-866.8000
190	-863.2000	0.01198392	0.00842652	0.01464993	-36.68	0.00884941	-863.2000
191	-859.6000	-0.00213058	0.00413683	0.00465325	-46.64	0.00887107	-859.6000
192	-856.0000	-0.00088369	-0.00000148	0.00088369	-61.07	0.00887185	-856.0000
193	-852.4000	-0.00012757	-0.00024453	0.00027581	-71.19	0.00887192	-852.4000
194	-848.8000	0.00007494	-0.00005052	0.00009037	-80.88	0.00887193	-848.8000
195	-845.2000	0.00001333	-0.00000934	0.00001627	-95.77	0.00887193	-845.2000
196	-814.8000	-0.00006348	-0.00002429	0.00006797	-83.35	0.00887194	-814.8000
197	-811.2000	-0.00017310	-0.00045035	0.00048248	-66.33	0.00887217	-811.2000
198	-807.6000	0.00083310	0.00244394	0.00258204	-51.76	0.0088788[illegible]	-807.6000
199	-804.0000	-0.00871747	0.00490735	0.01000382	-40.00	0.00897891	-804.0000
200	-800.4000	-0.02212805	0.01083600	0.02463878	-32.17	0.00958598	-800.4000
201	-796.8000	-0.01391035	0.01961761	0.02404887	-32.38	0.01016433	-796.8000
202	-793.2000	-0.00641544	0.00912302	0.01115356	-39.05	0.01028873	-793.2000
203	-789.6000	-0.00134806	-0.00069429	0.00151635	-56.38	0.01029103	-789.6000
204	-786.0000	0.00000031	-0.00018555	0.00018555	-74.63	0.01029107	-786.0000
205	-782.4000	0.00003801	-0.00001983	0.00004287	-87.36	0.01029107	-782.4000
206	-778.8000	0.00000624	0.00000926	0.00001117	-99.04	0.01029107	-778.8000
207	-748.4000	0.00002370	-0.00007086	0.00007473	-82.53	0.01029107	-748.4000
208	-744.8000	-0.00019664	0.00051979	0.00055013	-65.19	0.01029138	-744.8000
209	-741.2000	-0.00289751	0.00111368	0.00310416	-50.16	0.01030101	-741.2000
210	-737.6000	0.01163953	-0.00396774	0.01229722	-38.20	0.01045223	-737.6000
211	-734.0000	0.01505999	0.02475145	0.03069890	-30.26	0.01139466	-734.0000
212	-730.4000	0.01423282	0.02993465	0.03234243	-29.80	0.01244198	-730.4000
213	-726.8000	-0.01493565	-0.01059049	0.01830934	-34.75	0.01277721	-726.8000
214	-723.2000	-0.00297317	-0.00209059	0.00363460	-48.79	0.01279042	-723.2000
215	-719.6000	0.00014578	-0.00028305	0.00031839	-69.94	0.01279053	-719.6000
216	-716.0000	0.00002884	0.00000005	0.00002884	-90.80	0.01279053	-716.0000
217	-712.4000	0.00000245	0.00000470	0.00000530	-105.52	0.01279053	-712.4000
218	-682.0000	-0.00004038	0.00007073	0.00008144	-81.78	0.01279053	-682.0000
219	-678.4000	-0.00057368	-0.00019186	0.00060491	-64.37	0.01279090	-678.4000
220	-674.8000	0.00330566	0.00126512	0.00353948	-49.02	0.01280343	-674.8000
221	-671.2000	0.00530402	0.01379968	0.01478391	-36.60	0.01302199	-671.2000
222	-667.6000	-0.01217587	-0.03571845	0.03773671	-28.46	0.01444605	-667.6000
223	-664.0000	0.03513738	-0.01978001	0.04032225	-27.89	0.01607193	-664.0000
224	-660.4000	-0.02212805	0.01083600	0.02463878	-32.17	0.01667900	-660.4000
225	-656.8000	0.00345111	-0.00486706	0.00596644	-44.49	0.01671460	-656.8000

ARRAY SIZE: 900 LINES; LINES FILLED: 665

LINE	FREQ	REAL	IMAG	AMPLITUDE	DB	SUM OF POWER	FREQ
226	-653.2000	0.00043896	-0.00062427	0.00076315	-62.35	0.01671519	-653.2000
227	-649.6000	0.00004399	0.00002266	0.00004949	-86.11	0.01671519	-649.6000
228	-646.0000	-0.00000001	0.00000356	0.00000356	-108.96	0.01671519	-646.0000
229	-615.6000	0.00007882	0.00004026	0.00008851	-81.06	0.01671520	-615.6000
230	-612.0000	0.00057250	0.00032684	0.00065922	-63.62	0.01671563	-612.0000
231	-608.4000	-0.00123442	0.00369094	0.00389189	-48.20	0.01673078	-608.4000
232	-604.8000	0.00602526	-0.01574353	0.01685712	-35.46	0.01701494	-604.8000
233	-601.2000	0.04234736	-0.01627656	0.04536767	-26.87	0.01907316	-601.2000
234	-597.6000	-0.04691530	0.01599270	0.04956624	-26.10	0.02152998	-597.6000
235	-594.0000	0.01505929	0.02675145	0.03069890	-30.26	0.02247240	-594.0000
236	-590.4000	-0.00353112	-0.00721084	0.00802901	-41.91	0.02253686	-590.4000
237	-586.8000	0.00102193	0.00072463	0.00125277	-58.04	0.02253843	-586.8000
238	-583.2000	0.00009703	0.00006823	0.00011862	-78.52	0.02253845	-583.2000
239	-579.6000	-0.00000280	0.00000544	0.00000611	-104.27	0.02253845	-579.6000
240	-549.2000	0.00007598	-0.00005490	0.00009374	-80.56	0.02253846	-549.2000
241	-545.6000	0.00032584	-0.00063801	0.00071640	-62.90	0.02253897	-545.6000
242	-542.0000	0.00210280	-0.00368336	0.00424134	-47.45	0.02255696	-542.0000
243	-538.4000	0.01757848	0.00587903	0.01853553	-34.64	0.02290052	-538.4000
244	-534.8000	-0.04831249	-0.01848982	0.05172977	-25.73	0.02557649	-534.8000
245	-531.2000	-0.02137887	-0.05562221	0.0595.331	-24.50	0.02912738	-531.2000
246	-527.6000	-0.01217587	-0.03571845	0.03773671	-28.46	0.03055144	-527.6000
247	-524.0000	-0.00871747	0.00490735	0.01000382	-40.00	0.03065152	-524.0000
248	-520.4000	0.00151405	-0.00074143	0.00168584	-55.46	0.03065436	-520.4000
249	-516.8000	-0.00011263	0.00015884	0.00019472	-74.21	0.03065440	-516.8000
250	-513.2000	-0.00000843	0.00001199	0.00001465	-96.68	0.03065440	-513.2000
251	-482.8000	0.00005937	0.00007595	0.00009640	-80.32	0.03065441	-482.8000
252	-479.2000	-0.00044439	-0.00061498	0.00075874	-62.40	0.03065498	-479.2000
253	-475.6000	-0.00410486	-0.00209641	0.00460921	-46.73	0.03067623	-475.6000
254	-472.0000	-0.01754240	-0.01001482	0.02019981	-33.89	0.03108426	-472.0000
255	-468.4000	0.01804110	-0.05394341	0.05688034	-24.90	0.03431963	-468.4000
256	-464.8000	-0.02428592	0.06345726	0.06794579	-23.36	0.03893626	-464.8000
257	-461.2000	0.04234736	-0.01627656	0.04536767	-26.87	0.04099449	-461.2000
258	-457.6000	0.01163953	-0.00396774	0.01229722	-38.20	0.04114571	-457.6000
259	-454.0000	-0.00103039	-0.00183040	0.00210049	-53.55	0.04115012	-454.0000
260	-450.4000	0.00011524	0.00023533	0.00026203	-71.63	0.04115019	-450.4000
261	-446.8000	-0.00001962	-0.00001391	0.00002406	-92.38	0.04115019	-446.8000
262	-416.4000	0.00004377	0.00008767	0.00009799	-80.18	0.04115020	-416.4000
263	-412.8000	0.00061472	-0.00048054	0.00078025	-62.16	0.04115081	-412.8000
264	-409.2000	-0.00395670	0.00285914	0.00488162	-46.23	0.04117464	-409.2000
265	-405.6000	-0.00998435	0.01954982	0.02195183	-33.17	0.04165652	-405.6000
266	-402.0000	-0.03073268	0.05383270	0.06198756	-24.15	0.04549898	-402.0000
267	-398.4000	-0.07085335	-0.02369454	0.07471093	-22.53	0.05108070	-398.4000
268	-394.8000	-0.04831249	-0.01848982	0.05172977	-25.73	0.05375667	-394.8000
269	-391.2000	0.00530402	0.01379968	0.01478391	-36.60	0.05397523	-391.2000
270	-387.6000	0.00083310	0.00244394	0.00258204	-51.76	0.05398190	-387.6000

ARRAY SIZE: 900 LINES; LINES FILLED: 665

LINE	FREQ	REAL	IMAG	AMPLITUDE	DB	SUM OF POWER	FREQ
271	-384.0000	0.00028450	-0.00016015	0.00032648	-69.72	0.05398201	-384.0000
272	-380.4000	-0.00002907	0.00001424	0.00003237	-89.80	0.05398201	-380.4000
273	-350.0000	-0.00002487	0.00054903	0.00054960	-65.20	0.05398231	-350.0000
274	-346.4000	0.00070960	-0.00035427	0.00079312	-62.01	0.05398294	-346.4000
275	-342.8000	-0.00309171	-0.00395498	0.00502002	-45.99	0.05400814	-342.8000
276	-339.2000	0.01361696	0.01884421	0.02324921	-32.67	0.05454867	-339.2000
277	-335.6000	0.05999292	0.03063918	0.06736401	-23.43	0.05908658	-335.6000
278	-332.0000	0.07070793	0.04036662	0.08141914	-21.79	0.06571565	-332.0000
279	-328.4000	0.01804110	-0.05394341	0.05688034	-24.90	0.06895103	-328.4000
280	-324.8000	0.00602526	-0.01574353	0.01685712	-35.46	0.06923519	-324.8000
281	-321.2000	-0.00289751	0.00111368	0.00310416	-50.16	0.06924482	-321.2000
282	-317.6000	-0.00037986	0.00012949	0.00040132	-67.93	0.06924498	-317.6000
283	-314.0000	0.00001979	0.00003515	0.00004033	-87.89	0.06924499	-314.0000
284	-283.6000	0.00004432	-0.00008913	0.00009954	-80.04	0.06924500	-283.6000
285	-280.0000	0.00444395	0.00020133	0.00444851	-47.04	0.06926479	-280.0000
286	-276.4000	-0.00227934	-0.00456546	0.00510283	-45.84	0.06929082	-276.4000
287	-272.8000	-0.01883602	0.01472460	0.02390835	-32.43	0.06986243	-272.8000
288	-269.2000	0.05782759	-0.04178663	0.07134530	-22.93	0.07495259	-269.2000
289	-265.6000	0.04024381	-0.07879923	0.08848097	-21.06	0.08278147	-265.6000
290	-262.0000	-0.03073268	0.05383270	0.06198756	-24.15	0.08662393	-262.0000
291	-258.4000	0.01757848	0.00587903	0.01853553	-34.64	0.08696749	-258.4000
292	-254.8000	0.00330566	0.00126512	0.00353948	-49.02	0.08698002	-254.8000
293	-251.2000	-0.00017310	-0.00045035	0.00048248	-66.33	0.08698025	-251.2000
294	-247.6000	-0.00001600	-0.00004693	0.00004956	-86.09	0.08698025	-247.6000
295	-217.2000	0.00006077	-0.00007525	0.00009672	-80.29	0.08698026	-217.2000
296	-213.6000	-0.00072146	-0.00035873	0.00080573	-61.88	0.08698091	-213.6000
297	-210.0000	0.00129535	-0.02859161	0.02862094	-30.87	0.08780007	-210.0000
298	-206.4000	-0.02174349	0.01085560	0.02430274	-32.29	0.08839070	-206.4000
299	-202.8000	0.04518565	0.05780246	0.07336803	-22.69	0.09377356	-202.8000
300	-199.2000	-0.05488571	-0.07595512	0.09371030	-20.56	0.10255518	-199.2000
301	-195.6000	0.05999292	0.03063918	0.06736401	-23.43	0.10709309	-195.6000
302	-192.0000	-0.01754240	-0.01001482	0.02019981	-33.89	0.10750113	-192.0000
303	-188.4000	-0.00123442	0.00369094	0.00389189	-48.20	0.10751627	-188.4000
304	-184.8000	-0.00019664	0.00051379	0.00055013	-65.19	0.10751658	-184.8000
305	-181.2000	0.00005564	-0.00002139	0.00005961	-84.49	0.10751658	-181.2000
306	-150.8000	0.00007448	0.00005443	0.00009225	-80.70	0.10751659	-150.8000
307	-147.2000	-0.00060906	-0.00049185	0.00078286	-62.13	0.10751720	-147.2000
308	-143.6000	-0.00230801	0.00464175	0.00518390	-45.71	0.10754407	-143.6000
309	-140.0000	-0.13617055	-0.00616924	0.13631023	-17.31	0.12612455	-140.0000
310	-136.4000	0.03331279	0.06672466	0.07457829	-22.55	0.13168647	-136.4000
311	-132.8000	0.07592211	-0.05935025	0.09636710	-20.32	0.14097309	-132.8000
312	-129.2000	0.05782759	-0.04178663	0.07134530	-22.93	0.14604324	-129.2000
313	-125.6000	-0.00998435	0.01954982	0.02195183	-33.17	0.14654513	-125.6000
314	-122.0000	0.00210280	-0.00368336	0.00424134	-47.45	0.14656312	-122.0000
315	-118.4000	-0.00057368	-0.00019186	0.00060491	-64.37	0.14656348	-118.4000

ARRAY SIZE: 900 LINES; LINES FILLED: 665

LINE	FREQ	REAL	IMAG	AMPLITUDE	DB	SUM OF POWER	FREQ
316	-114.8000	-0.00006348	-0.00002429	0.00006797	-83.35	0.14656349	-114.8000
317	-84.4000	0.00007756	-0.00004125	0.00008785	-81.13	0.14656349	-84.4000
318	-80.8000	0.00044060	-0.00060282	0.00074667	-62.54	0.14656405	-80.8000
319	-77.2000	-0.00316447	0.00391861	0.00503680	-45.96	0.14658942	-77.2000
320	-73.6000	0.02210684	0.01099216	0.02468886	-32.15	0.14719896	-73.6000
321	-70.0000	-0.01893168	0.41786920	0.41829783	-7.57	0.32217203	-70.0000
322	-66.4000	0.08764120	-0.04375553	0.09795676	-20.18	0.33176756	-66.4000
323	-62.8000	0.04518565	0.05780246	0.07336803	-22.69	0.33715043	-62.8000
324	-59.2000	0.01361696	0.01884421	0.02324921	-32.67	0.33769095	-59.2000
325	-55.6000	-0.00410486	-0.00209641	0.00460921	-46.73	0.33771220	-55.6000
326	-52.0000	0.00057250	0.00032684	0.00065922	-63.62	0.33771263	-52.0000
327	-48.4000	0.00002370	-0.00007088	0.00007473	-82.53	0.33771264	-48.4000
328	-18.0000	-0.00004178	-0.00007157	0.00008288	-81.63	0.33771265	-18.0000
329	-14.4000	-0.00033392	-0.00062776	0.00071105	-62.96	0.33771315	-14.4000
330	-10.8000	-0.00387842	-0.00283475	0.00480395	-46.37	0.33773623	-10.8000
331	-7.2000	0.01866276	0.01507110	0.02398827	-32.40	0.33831167	-7.2000
332	-3.6000	0.03373186	-0.06783969	0.07576320	-22.41	0.34405173	-3.6000
333	0.0000	0.54886092	0.02486630	0.54942392	-5.20	0.64591837	0.0000
334	3.6000	0.03331279	0.06672466	0.07457829	-22.55	0.65148030	3.6000
335	7.2000	-0.01883602	0.01472460	0.02390835	-32.43	0.65205191	7.2000
336	10.8000	-0.00395670	0.00285914	0.00488162	-46.23	0.65207574	10.8000
337	14.4000	0.00032584	-0.00063801	0.00071640	-62.90	0.65207625	14.4000
338	18.0000	-0.00004038	0.00007073	0.00008144	-81.78	0.65207626	18.0000
339	48.4000	0.00002276	0.00007216	0.00007566	-82.42	0.65207626	48.4000
340	52.0000	-0.00057934	0.00033820	0.00067083	-63.47	0.65207671	52.0000
341	55.6000	-0.00403891	0.00214837	0.00457475	-46.79	0.65209764	55.6000
342	59.2000	-0.01350077	0.01847139	0.02287932	-32.81	0.65262110	59.2000
343	62.8000	0.04624896	-0.05727084	0.07361328	-22.66	0.65804002	62.8000
344	66.4000	-0.08910577	-0.04430596	0.09951310	-20.04	0.66794287	66.4000
345	70.0000	-0.01893168	0.41786920	0.41829783	-7.57	0.84291595	70.0000
346	73.6000	-0.02174349	0.01085560	0.02430274	-32.29	0.84350657	73.6000
347	77.2000	-0.00309171	-0.00395498	0.00502002	-45.99	0.84353177	77.2000
348	80.8000	-0.00044439	-0.00061498	0.00075874	-62.40	0.84353235	80.8000
349	84.4000	0.00007882	0.00004026	0.00008851	-81.06	0.84353236	84.4000
350	114.8000	-0.00006275	0.00002284	0.00006678	-83.51	0.84353236	114.8000
351	118.4000	0.00058403	-0.00018418	0.00061239	-64.26	0.84353274	118.4000
352	122.0000	0.00217595	0.00372735	0.00431601	-47.30	0.84355136	122.0000
353	125.6000	0.01023183	0.01923574	0.02178771	-33.24	0.84402607	125.6000
354	129.2000	0.05668353	0.04143008	0.07021021	-23.07	0.84895554	129.2000
355	132.8000	-0.07522384	-0.06074687	0.09668924	-20.29	0.85830435	132.8000
356	136.4000	0.03373186	-0.06783969	0.07576320	-22.41	0.86404441	136.4000
357	140.0000	-0.13617055	-0.00616924	0.13631023	-17.31	0.88262489	140.0000
358	143.6000	-0.00227934	-0.00456546	0.00510283	-45.84	0.88265093	143.6000
359	147.2000	0.00061472	-0.00048054	0.00078025	-62.16	0.88265154	147.2000
360	150.8000	0.00007598	-0.00005490	0.00009374	-80.56	0.88265154	150.8000

ARRAY SIZE: 900 LINES; LINES FILLED: 665

LINE	FREQ	REAL	IMAG	AMPLITUDE	DB	SUM OF POWER	FREQ
361	181.2000	0.00005483	0.00001987	0.00005831	-84.68	0.88265155	181.2000
362	184.8000	0.00018490	0.00050790	0.00054051	-65.34	0.88265184	184.8000
363	188.4000	-0.00118500	-0.00375758	0.00394000	-48.09	0.88266736	188.4000
364	192.0000	0.01775190	-0.01036318	0.02055543	-33.74	0.88308989	192.0000
365	195.6000	0.05902909	-0.03139863	0.06686036	-23.50	0.88756020	195.6000
366	199.2000	0.05441739	-0.07445242	0.09221938	-20.70	0.89606461	199.2000
367	202.8000	0.04624896	-0.05727084	0.07361328	-22.66	0.90148353	202.8000
368	206.4000	0.02210684	0.01099216	0.02468886	-32.15	0.90209307	206.4000
369	210.0000	0.00129535	-0.02859161	0.02862094	-30.87	0.90291223	210.0000
370	213.6000	0.00070960	-0.00035427	0.00079312	-62.01	0.90291285	213.6000
371	217.2000	0.00005937	0.00007595	0.00009640	-80.32	0.90291286	217.2000
372	247.6000	-0.00001498	0.00004836	0.00005062	-85.91	0.90291287	247.6000
373	251.2000	0.00016082	-0.00044377	0.00047201	-66.52	0.90291309	251.2000
374	254.8000	0.00326774	-0.00118960	0.00347754	-49.17	0.90292518	254.8000
375	258.4000	-0.01789585	0.00564368	0.01876467	-34.53	0.90327729	258.4000
376	262.0000	-0.03180171	-0.05447561	0.06307885	-24.00	0.90725624	262.0000
377	265.6000	-0.04124132	-0.07753326	0.08781944	-21.13	0.91496849	265.6000
378	269.2000	0.05668353	0.04143008	0.07021021	-23.07	0.91989796	269.2000
379	272.8000	0.01866278	0.01507110	0.02398827	-32.40	0.92047340	272.8000
380	276.4000	-0.00230801	0.00464175	0.00518390	-45.71	0.92050027	276.4000
381	280.0000	0.00444395	0.00020133	0.00444851	-47.04	0.92052006	280.0000
382	283.6000	0.00004377	0.00008767	0.00009799	-80.18	0.92052007	283.6000
383	314.0000	0.00002128	-0.00003598	0.00004180	-87.58	0.92052007	314.0000
384	317.6000	0.00039141	0.00012124	0.00040975	-67.75	0.92052024	317.6000
385	321.2000	-0.00285512	-0.00103467	0.00303681	-50.35	0.92052946	321.2000
386	324.8000	-0.00566561	-0.01556295	0.01656214	-35.62	0.92080377	324.8000
387	328.4000	0.01731886	0.05491735	0.05758349	-24.79	0.92411963	328.4000
388	332.0000	-0.07155238	0.04177076	0.08285251	-21.63	0.93098417	332.0000
389	335.6000	0.05902909	-0.03139863	0.06686036	-23.50	0.93545447	335.6000
390	339.2000	-0.01350077	0.01847139	0.02287932	-32.81	0.93597794	339.2000
391	342.8000	-0.00316447	0.00391861	0.00503680	-45.96	0.93600331	342.8000
392	346.4000	-0.00072146	-0.00035873	0.00080573	-61.88	0.93600395	346.4000
393	350.0000	-0.00002487	0.00054903	0.00054960	-65.20	0.93600426	350.0000
394	380.4000	-0.00002771	-0.00001532	0.00003167	-89.99	0.93600426	380.4000
395	384.0000	-0.00029125	-0.00017223	0.00033836	-69.41	0.93600437	384.0000
396	387.6000	0.00078001	-0.00251824	0.00263627	-51.58	0.93601132	387.6000
397	391.2000	-0.00492771	0.01359779	0.01446313	-36.79	0.93622050	391.2000
398	394.8000	-0.04775831	0.01738618	0.05082456	-25.88	0.93880364	394.8000
399	398.4000	0.07213259	-0.02274790	0.07563450	-22.43	0.94452422	398.4000
400	402.0000	-0.03180171	-0.05447561	0.06307885	-24.00	0.94850316	402.0000
401	405.6000	0.01023183	0.01923574	0.02178771	-33.24	0.94897786	405.6000
402	409.2000	-0.00387842	-0.00283475	0.00480395	-46.37	0.94900094	409.2000
403	412.8000	-0.00060906	-0.00049185	0.00078286	-62.13	0.94900155	412.8000
404	416.4000	0.00004432	-0.00008913	0.00009954	-80.04	0.94900156	416.4000
405	446.8000	-0.00001795	0.00001336	0.00002237	-93.01	0.94900156	446.8000

ARRAY SIZE: 900 LINES; LINES FILLED: 665

LINE	FREQ	REAL	IMAG	AMPLITUDE	DB	SUM OF POWER	FREQ
406	450.4000	-0.00012404	0.00022431	0.00025632	-71.82	0.94900163	450.4000
407	454.0000	-0.00110809	0.00187384	0.00217695	-53.24	0.94900637	454.0000
408	457.6000	-0.01199338	-0.00371486	0.01255553	-38.02	0.94916401	457.6000
409	461.2000	0.04172779	0.01512175	0.04438328	-27.06	0.95113388	461.2000
410	464.8000	0.02283632	0.06272937	0.06675681	-23.51	0.95559036	464.8000
411	468.4000	0.01731886	0.05491735	0.05758349	-24.79	0.95890621	468.4000
412	472.0000	0.01775190	-0.01036318	0.02055543	-33.74	0.95932874	472.0000
413	475.6000	-0.00403891	0.00214837	0.00457475	-46.79	0.95934967	475.6000
414	479.2000	0.00044060	-0.00060282	0.00074667	-62.54	0.95935023	479.2000
415	482.8000	0.00006077	-0.00007525	0.00009672	-80.29	0.95935024	482.8000
416	513.2000	-0.00001002	-0.00001120	0.00001503	-96.46	0.95935024	513.2000
417	516.8000	0.00010812	0.00014525	0.00018107	-74.84	0.95935027	516.8000
418	520.4000	0.00144315	0.00079803	0.00164910	-55.66	0.95935299	520.4000
419	524.0000	0.00892436	0.00527737	0.01036797	-39.69	0.95946048	524.0000
420	527.6000	0.01139987	0.03680430	0.03852939	-28.28	0.96094500	527.6000
421	531.2000	0.01986204	-0.05480842	0.05829634	-24.69	0.96434346	531.2000
422	534.8000	-0.04775831	0.01738618	0.05082456	-25.88	0.96692660	534.8000
423	538.4000	-0.01789585	0.00564368	0.01876467	-34.53	0.96727871	538.4000
424	542.0000	0.00217595	0.00372735	0.00431601	-47.30	0.96729734	542.0000
425	545.6000	-0.00033392	-0.00062776	0.00071105	-62.96	0.96729784	545.6000
426	549.2000	0.00007448	0.00005443	0.00009225	-80.70	0.96729785	549.2000
427	579.6000	-0.00000343	-0.00000710	0.00000789	-102.06	0.96729785	579.6000
428	583.2000	-0.00009062	0.00008112	0.00012163	-78.30	0.96729787	583.2000
429	586.8000	0.00093452	-0.00069562	0.00116500	-58.67	0.96729922	586.8000
430	590.4000	0.00380069	-0.00687316	0.00785401	-42.10	0.96736091	590.4000
431	594.0000	0.01619478	-0.02738636	0.03181640	-29.95	0.96837319	594.0000
432	597.6000	0.04834155	0.01497345	0.05060741	-25.92	0.97093430	597.6000
433	601.2000	0.04172779	0.01512175	0.04438328	-27.06	0.97290418	601.2000
434	604.8000	-0.00566561	-0.01556295	0.01656214	-35.62	0.97317848	604.8000
435	608.4000	-0.00118500	-0.00375758	0.00394000	-48.09	0.97319400	608.4000
436	612.0000	-0.00057934	0.00033820	0.00067083	-63.47	0.97319445	612.0000
437	615.6000	0.00007756	-0.00004125	0.00008785	-81.13	0.97319446	615.6000
438	646.0000	-0.00000001	0.00000356	0.00000356	-108.96	0.97319446	646.0000
439	649.6000	-0.00005750	0.00002774	0.00006384	-83.90	0.97319447	649.6000
440	653.2000	0.00052192	0.00058303	0.00078251	-62.13	0.97319508	653.2000
441	656.8000	-0.00331298	-0.00445077	0.00554844	-45.12	0.97322586	656.8000
442	660.4000	-0.02109178	-0.01166324	0.02410175	-32.36	0.97380676	660.4000
443	664.0000	-0.03597131	-0.02127144	0.04179006	-27.58	0.97555317	664.0000
444	667.6000	-0.01139987	0.03680430	0.03852939	-28.28	0.97703768	667.6000
445	671.2000	-0.00492771	0.01359779	0.01446313	-36.79	0.97724686	671.2000
446	674.8000	0.00326774	-0.00118960	0.00347754	-49.17	0.97725896	674.8000
447	678.4000	0.00058403	-0.00018418	0.00061239	-64.26	0.97725933	678.4000
448	682.0000	-0.00004178	-0.00007157	0.00008288	-81.63	0.97725934	682.0000
449	712.4000	0.00000307	-0.00000635	0.00000706	-103.03	0.97725934	712.4000
450	716.0000	0.00002884	0.00000005	0.00002884	-90.80	0.97725934	716.0000

ARRAY SIZE: 900 LINES; LINES FILLED: 665

LINE	FREQ	REAL	IMAG	AMPLITUDE	DB	SUM OF POWER	FREQ
451	719.6000	0.00017847	0.00036991	0.00041072	-67.73	0.97725951	719.6000
452	723.2000	0.00277675	-0.00248572	0.00372681	-48.57	0.97727340	723.2000
453	726.8000	-0.01365817	0.01016661	0.01702661	-35.38	0.97756330	726.8000
454	730.4000	-0.01531938	0.02770354	0.03165706	-29.99	0.97856547	730.4000
455	734.0000	0.01619478	0.02738636	0.03181640	-29.95	0.97957776	734.0000
456	737.6000	-0.01199338	-0.00371486	0.01255553	-38.02	0.97973540	737.6000
457	741.2000	-0.00285512	-0.00103467	0.00303681	-50.35	0.97974462	741.2000
458	744.8000	0.00018490	0.00050790	0.00054051	-65.34	0.97974491	744.8000
459	748.4000	0.00002276	0.00007216	0.00007565	-82.42	0.97974492	748.4000
460	778.8000	0.00000782	-0.00000847	0.00001152	-98.77	0.97974492	778.8000
461	782.4000	-0.00005142	-0.00002487	0.00005712	-84.86	0.97974492	782.4000
462	786.0000	0.00000030	-0.00018555	0.00018555	-74.63	0.97974495	786.0000
463	789.6000	0.00176175	-0.00084999	0.00195608	-54.17	0.97974878	789.6000
464	793.2000	-0.00762796	-0.00852105	0.01143653	-38.83	0.97987957	793.2000
465	796.8000	0.01335359	0.01793967	0.02236404	-33.01	0.98037973	796.8000
466	800.4000	-0.02109178	-0.01166324	0.02410175	-32.36	0.98096062	800.4000
467	804.0000	0.00892436	0.00527737	0.01036797	-39.69	0.98106811	804.0000
468	807.6000	0.00078001	-0.00251824	0.00263627	-51.58	0.98107506	807.6000
469	811.2000	0.00016082	-0.00044377	0.00047201	-66.52	0.98107529	811.2000
470	814.8000	-0.00006275	0.00002284	0.00006678	-83.51	0.98107529	814.8000
471	845.2000	0.00001162	0.00000881	0.00001458	-96.73	0.98107529	845.2000
472	848.8000	-0.00006852	-0.00006330	0.00009328	-80.60	0.98107530	848.8000
473	852.4000	-0.00015999	0.00033082	0.00036748	-68.70	0.98107544	852.4000
474	856.0000	-0.00088370	-0.00000144	0.00088371	-61.07	0.98107622	856.0000
475	859.6000	-0.00260838	-0.00540633	0.00600267	-44.43	0.98111225	859.6000
476	863.2000	-0.01119220	0.01001914	0.01502160	-36.47	0.98133790	863.2000
477	866.8000	-0.01365817	0.01016661	0.01702661	-35.38	0.98162780	866.8000
478	870.4000	0.00380069	-0.00687316	0.00785401	-42.10	0.98168949	870.4000
479	874.0000	-0.00110809	0.00187384	0.00217695	-53.24	0.98169423	874.0000
480	877.6000	0.00039141	0.00012124	0.00040975	-67.75	0.98169440	877.6000
481	881.2000	0.00005483	0.00001987	0.00005831	-84.68	0.98169440	881.2000
482	911.6000	0.00001566	-0.00000912	0.00001812	-94.84	0.98169440	911.6000
483	915.2000	0.00007129	-0.00009403	0.00011800	-78.56	0.98169441	915.2000
484	918.8000	-0.00040724	0.00044086	0.00060017	-64.43	0.98169477	918.8000
485	922.4000	0.00157557	0.00076198	0.00175016	-55.14	0.98169784	922.4000
486	926.0000	-0.00000442	0.00271184	0.00271184	-51.33	0.98170519	926.0000
487	929.6000	-0.00710108	0.00342604	0.00788436	-42.06	0.98176735	929.6000
488	933.2000	-0.00762796	-0.00852105	0.01143653	-38.83	0.98189815	933.2000
489	936.8000	-0.00331298	-0.00445077	0.00554844	-45.12	0.98192893	936.8000
490	940.4000	0.00144315	0.00079803	0.00164910	-55.66	0.98193165	940.4000
491	944.0000	-0.00029125	-0.00017223	0.00033836	-69.41	0.98193177	944.0000
492	947.6000	-0.00001498	0.00004836	0.00005062	-85.91	0.98193177	947.6000
493	978.0000	-0.00001102	-0.00001818	0.00002126	-93.45	0.98193177	978.0000
494	981.6000	-0.00007381	-0.00012676	0.00014669	-76.67	0.98193179	981.6000
495	985.2000	-0.00060495	-0.00045867	0.00075917	-62.39	0.98193237	985.2000

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496	988.8000	0.00209965	0.00193953	0.00285837	-50.88	0.98194054	988.8000
497	992.4000	0.00233831	-0.00483499	0.00537074	-45.40	0.98196938	992.4000
498	996.0000	0.00356194	0.00000581	0.00356194	-48.97	0.98198207	996.0000
499	999.6000	-0.00260838	-0.00540633	0.00600267	-44.43	0.98201810	999.6000
500	1003.2000	0.00277675	-0.00248572	0.00372681	-48.57	0.98203199	1003.2000
501	1006.8000	0.00093452	-0.00069562	0.00116500	-58.67	0.98203335	1006.8000
502	1010.4000	-0.00012404	0.00022431	0.00025632	-71.82	0.98203341	1010.4000
503	1014.0000	0.00002128	-0.00003598	0.00004180	-87.58	0.98203342	1014.0000
504	1044.4000	0.00000606	0.00002107	0.00002192	-93.18	0.98203342	1044.4000
505	1048.0000	-0.00014712	0.00008920	0.00017205	-75.29	0.98203345	1048.0000
506	1051.6000	-0.00081558	0.00047490	0.00094377	-60.50	0.98203434	1051.6000
507	1055.2000	-0.00218445	0.00288115	0.00361564	-48.84	0.98204741	1055.2000
508	1058.8000	0.00595187	-0.00644324	0.00877155	-41.14	0.98212435	1058.8000
509	1062.4000	-0.00635064	-0.00307131	0.00705433	-43.03	0.98217411	1062.4000
510	1066.0000	-0.00000442	0.00271184	0.00271184	-51.33	0.98218147	1066.0000
511	1069.6000	0.00176175	-0.00084999	0.00195608	-54.17	0.98218529	1069.6000
512	1073.2000	0.00052192	0.00058303	0.00078251	-62.13	0.98218591	1073.2000
513	1076.8000	0.00010812	0.00014525	0.00018107	-74.84	0.98218594	1076.8000
514	1080.4000	-0.00002771	-0.00001532	0.00003167	-89.99	0.98218594	1080.4000
515	1110.8000	-0.00001956	0.00000462	0.00002065	-93.70	0.98218594	1110.8000
516	1114.4000	0.00017054	-0.00004902	0.00017744	-75.02	0.98218597	1114.4000
517	1118.0000	0.00057392	0.00094653	0.00110693	-59.12	0.98218720	1118.0000
518	1121.6000	0.00226177	0.00388429	0.00449481	-46.95	0.98220740	1121.6000
519	1125.2000	0.00884144	0.00670345	0.01109537	-39.10	0.98233051	1125.2000
520	1128.8000	-0.00846303	-0.00781764	0.01152121	-38.77	0.98246325	1128.8000
521	1132.4000	0.00233831	-0.00483499	0.00537074	-45.40	0.98249209	1132.4000
522	1136.0000	-0.00088370	-0.00000144	0.00088371	-61.07	0.98249287	1136.0000
523	1139.6000	0.00017847	0.00036991	0.00041072	-67.73	0.98249304	1139.6000
524	1143.2000	-0.00009062	0.00008112	0.00012163	-78.30	0.98249306	1143.2000
525	1146.8000	-0.00001795	0.00001336	0.00002237	-93.01	0.98249306	1146.8000
526	1177.2000	0.00001866	0.00000626	0.00001968	-94.12	0.98249306	1177.2000
527	1180.8000	0.00005362	0.00015835	0.00016718	-75.54	0.98249308	1180.8000
528	1184.4000	-0.00031542	-0.00109720	0.00114163	-58.85	0.98249439	1184.4000
529	1188.0000	0.00450793	-0.00273336	0.00527188	-45.56	0.98252218	1188.0000
530	1191.6000	0.01191981	-0.00694072	0.01379331	-37.21	0.98271244	1191.6000
531	1195.2000	0.00880482	-0.01161301	0.01457350	-36.73	0.98292482	1195.2000
532	1198.8000	0.00595187	-0.00644324	0.00877155	-41.14	0.98300176	1198.8000
533	1202.4000	0.00157557	0.00076198	0.00175016	-55.14	0.98300483	1202.4000
534	1206.0000	0.00000030	-0.00018555	0.00018555	-74.63	0.98300486	1206.0000
535	1209.6000	-0.00005750	0.00002774	0.00006384	-83.90	0.98300486	1209.6000
536	1213.2000	-0.00001002	-0.00001120	0.00001503	-96.46	0.98300486	1213.2000
537	1243.6000	-0.00000519	0.00001862	0.00001933	-94.28	0.98300486	1243.6000
538	1247.2000	0.00005069	-0.00015101	0.00015930	-75.96	0.98300489	1247.2000
539	1250.8000	0.00101879	-0.00034496	0.00107561	-59.37	0.98300605	1250.8000
540	1254.4000	-0.00522551	0.00150220	0.00543715	-45.29	0.98303561	1254.4000

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LINE	FREQ	REAL	IMAG	AMPLITUDE	DB	SUM OF POWER	FREQ
541	1258.0000	-0.00838793	-0.01383356	0.01617791	-35.82	0.98329733	1258.0000
542	1261.6000	-0.00911647	-0.01565638	0.01811718	-34.84	0.98362557	1261.6000
543	1265.2000	0.00884144	0.00670345	0.01109537	-39.10	0.98374867	1265.2000
544	1268.8000	0.00209965	0.00193953	0.00285837	-50.88	0.98375684	1268.8000
545	1272.4000	-0.00015999	0.00033082	0.00036748	-68.70	0.98375698	1272.4000
546	1276.0000	0.00002884	0.00000005	0.00002884	-90.80	0.98375698	1276.0000
547	1279.6000	-0.00000343	-0.00000710	0.00000789	-102.06	0.98375698	1279.6000
548	1310.0000	0.00000905	-0.00001466	0.00001723	-95.27	0.98375698	1310.0000
549	1313.6000	0.00015068	0.00004203	0.00015643	-76.11	0.98375700	1313.6000
550	1317.2000	-0.00097160	-0.00032615	0.00102488	-59.79	0.98375805	1317.2000
551	1320.8000	-0.00164289	-0.00485209	0.00512269	-45.81	0.98378430	1320.8000
552	1324.4000	0.00460983	0.01603563	0.01668508	-35.55	0.98406269	1324.4000
553	1328.0000	-0.01817004	0.01101734	0.02124928	-33.45	0.98451422	1328.0000
554	1331.6000	0.01191981	-0.00694072	0.01379331	-37.21	0.98470448	1331.6000
555	1335.2000	-0.00218445	0.00288115	0.00361564	-48.84	0.98471755	1335.2000
556	1338.8000	-0.00040724	0.00044086	0.00060017	-64.43	0.98471791	1338.8000
557	1342.4000	-0.00005142	-0.00002487	0.00005712	-84.86	0.98471791	1342.4000
558	1346.0000	-0.00000001	0.00000356	0.00000356	-108.96	0.98471791	1346.0000
559	1376.4000	-0.00001116	-0.00000685	0.00001310	-97.66	0.98471791	1376.4000
560	1380.0000	-0.00011868	-0.00007329	0.00013948	-77.11	0.98471793	1380.0000
561	1383.6000	0.00027039	-0.00096946	0.00100646	-59.94	0.98471895	1383.6000
562	1387.2000	-0.00155333	0.00462736	0.00488112	-46.23	0.98474277	1387.2000
563	1390.8000	-0.01488971	0.00504157	0.01572008	-36.07	0.98498989	1390.8000
564	1394.4000	0.02106240	-0.00605489	0.02191544	-33.18	0.98547018	1394.4000
565	1398.0000	-0.00838793	-0.01383356	0.01617791	-35.82	0.98573190	1398.0000
566	1401.6000	0.00226177	0.00388429	0.00449481	-46.95	0.98575211	1401.6000
567	1405.2000	-0.00060495	-0.00045867	0.00075917	-62.39	0.98575268	1405.2000
568	1408.8000	-0.00006852	-0.00006330	0.00009328	-80.60	0.98575269	1408.8000
569	1412.4000	0.00000307	-0.00000635	0.00000706	-103.03	0.98575269	1412.4000
570	1442.8000	-0.00000733	0.00000570	0.00000929	-100.64	0.98575269	1442.8000
571	1446.4000	-0.00005546	0.00009033	0.00010600	-79.49	0.98575270	1446.4000
572	1450.0000	-0.00047151	0.00076356	0.00089742	-60.94	0.98575351	1450.0000
573	1453.6000	-0.00461714	-0.00128778	0.00479337	-46.39	0.98577648	1453.6000
574	1457.2000	0.01420007	0.00476673	0.01497877	-36.49	0.98600085	1457.2000
575	1460.8000	0.00662198	0.01955727	0.02064794	-33.70	0.98642719	1460.8000
576	1464.4000	0.00460983	0.01603563	0.01668508	-35.55	0.98670558	1464.4000
577	1468.0000	0.00450793	-0.00273336	0.00527186	-45.56	0.98673337	1468.0000
578	1471.6000	-0.00081558	0.00047490	0.00094377	-60.50	0.98673426	1471.6000
579	1475.2000	0.00007129	-0.00009403	0.00011800	-78.56	0.98673427	1475.2000
580	1478.8000	0.00000782	-0.00000847	0.00001152	-98.77	0.98673427	1478.8000
581	1509.2000	-0.00000521	-0.00000488	0.00000714	-102.93	0.98673427	1509.2000
582	1512.8000	0.00004615	0.00005933	0.00007517	-82.48	0.98673428	1512.8000
583	1516.4000	0.00058117	0.00035679	0.00068195	-63.32	0.98673475	1516.4000
584	1520.0000	0.00363655	0.00224564	0.00427404	-47.38	0.98675301	1520.0000
585	1523.6000	-0.00395184	0.01416871	0.01470950	-36.65	0.98696938	1523.6000

ARRAY SIZE: 900 LINES; LINES FILLED: 665

LINE	FREQ	REAL	IMAG	AMPLITUDE	DB	SUM OF POWER	FREQ
586	1527.2000	0.00626099	-0.01865144	0.01967425	-34.12	0.98735646	1527.2000
587	1530.8000	-0.01488972	0.00504157	0.01572008	-36.07	0.98760358	1530.8000
588	1534.4000	-0.00522551	0.00150220	0.00543715	-45.29	0.98763314	1534.4000
589	1538.0000	0.00057392	0.00094653	0.00110693	-59.12	0.98763437	1538.0000
590	1541.6000	-0.00007381	-0.00012676	0.00014669	-76.67	0.98763439	1541.6000
591	1545.2000	0.00001162	0.00000881	0.00001458	-96.73	0.98763439	1545.2000
592	1575.6000	-0.00000186	-0.00000398	0.00000439	-107.14	0.98763439	1575.6000
593	1579.2000	-0.00003953	0.00004215	0.00005779	-84.76	0.98763439	1579.2000
594	1582.8000	0.00038174	-0.00029692	0.00048362	-66.31	0.98763463	1582.8000
595	1586.4000	0.00169927	-0.00276789	0.00324788	-49.77	0.98764518	1586.4000
596	1590.0000	0.00689123	-0.01115955	0.01311582	-37.64	0.98781720	1590.0000
597	1593.6000	0.01861025	0.00519064	0.01932057	-34.28	0.98819048	1593.6000
598	1597.2000	0.01420007	0.00476673	0.01497877	-36.49	0.98841485	1597.2000
599	1600.8000	-0.00164289	-0.00485209	0.00512269	-45.81	0.98844109	1600.8000
600	1604.4000	-0.00031542	-0.00109720	0.00114163	-58.85	0.98844239	1604.4000
601	1608.0000	-0.00014712	0.00008920	0.000172[illegible]5	-75.29	0.98844242	1608.0000
602	1611.6000	0.00001566	-0.00000912	0.00001812	-94.84	0.98844242	1611.6000
603	1642.0000	-0.00000001	0.00000424	0.00000424	-107.45	0.98844242	1642.0000
604	1645.6000	-0.00003224	0.00001502	0.00003557	-86.98	0.98844242	1645.6000
605	1649.2000	0.00027120	0.00025431	0.00037178	-68.59	0.98844256	1649.2000
606	1652.8000	-0.00141411	-0.00181808	0.00230329	-52.75	0.98844787	1652.8000
607	1656.4000	-0.00849386	-0.00521458	0.00996682	-40.03	0.98854721	1656.4000
608	1660.0000	-0.01465780	-0.00905146	0.01722730	-35.28	0.98884398	1660.0000
609	1663.6000	-0.00395184	0.01416871	0.01470950	-36.65	0.98906035	1663.6000
610	1667.2000	-0.00155333	0.00462736	0.00488112	-46.23	0.98908418	1667.2000
611	1670.8000	0.00101879	-0.00034496	0.00107561	-59.37	0.98908534	1670.8000
612	1674.4000	0.00017054	-0.00004902	0.00017744	-75.02	0.98908537	1674.4000
613	1678.0000	-0.00001102	-0.00001818	0.00002126	-93.45	0.98908537	1678.0000
614	1708.4000	0.00000180	-0.00000384	0.00000424	-107.45	0.98908537	1708.4000
615	1712.0000	0.00003432	0.00000005	0.00003432	-89.29	0.98908537	1712.0000
616	1715.6000	0.00009662	0.00020745	0.00022885	-72.81	0.98908542	1715.6000
617	1719.2000	0.00121117	-0.00129163	0.00177066	-55.04	0.98908856	1719.2000
618	1722.8000	-0.00557918	0.00433951	0.00706814	-43.01	0.98913852	1722.8000
619	1726.4000	-0.00684923	0.01115648	0.01309118	-37.66	0.98930989	1726.4000
620	1730.0000	0.00689123	-0.01115955	0.01311582	-37.64	0.98948192	1730.0000
621	1733.6000	-0.00461714	-0.00128778	0.00479337	-46.39	0.98950490	1733.6000
622	1737.2000	-0.00097160	-0.00032615	0.00102488	-59.79	0.98950595	1737.2000
623	1740.8000	0.00005362	0.00015835	0.00016718	-75.54	0.98950597	1740.8000
624	1744.4000	0.00000606	0.00002107	0.00002192	-93.18	0.98950597	1744.4000
625	1774.8000	0.00000465	-0.00000421	0.00000628	-104.04	0.98950597	1774.8000
626	1778.4000	-0.00003107	-0.00001459	0.00003432	-89.29	0.98950598	1778.4000
627	1782.0000	0.00000033	-0.00022081	0.00022081	-73.12	0.98950602	1782.0000
628	1785.6000	0.00098800	-0.00046016	0.00108990	-59.25	0.98950721	1785.6000
629	1789.2000	-0.00396365	-0.00371673	0.00543365	-45.30	0.98953674	1789.2000
630	1792.8000	0.00569984	0.00732812	0.00928383	-40.65	0.98962293	1792.8000

ARRAY SIZE: 900 LINES; LINES FILLED: 665

LINE	FREQ	REAL	IMAG	AMPLITUDE	DB	SUM OF POWER	FREQ
631	1796.4000	-0.00849386	-0.00521458	0.00996682	-40.03	0.98972226	1796.4000
632	1800.0000	0.00363655	0.00224564	0.00427404	-47.38	0.98974053	1800.0000
633	1803.6000	0.00027039	-0.00096946	0.00100646	-59.94	0.98974154	1803.6000
634	1807.2000	0.00005069	-0.00015101	0.00015930	-75.96	0.98974157	1807.2000
635	1810.8000	-0.00001956	0.00000662	0.00002065	-93.70	0.98974157	1810.8000
636	1841.2000	0.00000573	0.00000461	0.00000736	-102.67	0.98974157	1841.2000
637	1844.8000	-0.00003411	-0.00003766	0.00005081	-85.88	0.98974157	1844.8000
638	1848.4000	-0.00009387	0.00019987	0.00022082	-73.12	0.98974162	1848.4000
639	1852.0000	-0.00105162	-0.00000159	0.00105162	-59.56	0.98974273	1852.0000
640	1855.6000	-0.00141209	-0.00303189	0.00334460	-49.51	0.98975391	1855.6000
641	1859.2000	-0.00488183	0.00520615	0.00713697	-42.93	0.98980485	1859.2000
642	1862.8000	-0.00557918	0.00433951	0.00706814	-43.01	0.98985481	1862.8000
643	1866.4000	0.00169927	-0.00276789	0.00324788	-49.77	0.98986536	1866.4000
644	1870.0000	-0.00047151	0.00076356	0.00089742	-60.94	0.98986616	1870.0000
645	1873.6000	0.00015068	0.00004203	0.00015643	-76.11	0.98986619	1873.6000
646	1877.2000	0.00001866	0.00000626	0.00001968	-94.12	0.98986619	1877.2000
647	1907.6000	0.00000823	-0.00000545	0.00000987	-100.11	0.98986619	1907.6000
648	1911.2000	0.00003733	-0.00004639	0.00005955	-84.50	0.98986619	1911.2000
649	1914.8000	-0.00024228	0.00021948	0.00032692	-69.71	0.98986630	1914.8000
650	1918.4000	0.00095192	0.00044707	0.00105168	-59.56	0.98986740	1918.4000
651	1922.0000	-0.00000487	0.00322713	0.00322714	-49.82	0.98987782	1922.0000
652	1925.6000	-0.00398232	0.00185474	0.00439305	-47.14	0.98989712	1925.6000
653	1929.2000	-0.00396365	-0.00371673	0.00543365	-45.30	0.98992664	1929.2000
654	1932.8000	-0.00141411	-0.00181808	0.00230329	-52.75	0.98993195	1932.8000
655	1936.4000	0.00058117	0.00035679	0.00068195	-63.32	0.98993241	1936.4000
656	1940.0000	-0.00011868	-0.00007329	0.00013948	-77.11	0.98993243	1940.0000
657	1943.6000	-0.00000519	0.00001862	0.00001933	-94.28	0.98993243	1943.6000
658	1974.0000	-0.00000678	-0.00001064	0.00001262	-97.98	0.98993243	1974.0000
659	1977.6000	-0.00004414	-0.00006663	0.00007992	-81.95	0.98993244	1977.6000
660	1981.2000	-0.00029848	-0.00024017	0.00038311	-68.33	0.98993259	1981.2000
661	1984.8000	0.00104531	0.00115390	0.00155697	-56.15	0.98993501	1984.8000
662	1988.4000	0.00137194	-0.00292117	0.00322730	-49.82	0.98994543	1988.4000
663	1992.0000	0.00423876	0.00000640	0.00423876	-47.46	0.98996339	1992.0000
664	1995.6000	-0.00141209	-0.00303189	0.00334460	-49.51	0.98997458	1995.6000
665	1999.2000	0.00121117	-0.00129163	0.00177066	-55.04	0.98997771	1999.2000