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(1) Program Number (to be filled in by SPLA)........ 360D-16.0.002

(2) System Type (machine)........................ S/360, S/370

(3) Search Key.............................. Microwave Interference

(4) Programming Systems/Languages...... PL/I (F)

(5) Author's Name and Address.........

Mr. M. J. Pagones
Bell Laboratories
Bldg. WB Room 1A-202
Crawfords Corner Road
Holmdel, NJ 07733

(6) Direct Technical Inquiries to Name & Address
(if different than Author)

(7) Title of Program........... Programs for calculation of microwave interference

(8) Submitter's Installation Membership Code..... BTL

(9) Submitter's Own Program Identification and Suffix(Optional)..

(10) Primary Subject Code......................... 16.0

(11) Minimum System Requirements OS/360 (≈ 400K)

(12) New or Revision Code (if revision, show prior Program Number in Item 1) N

(13) Year Completed... 1971

(14) Date of Submittal.. 4/1/75

(15) Documentation (number of original pages submitted).......... 33

(16) Abstract (should contain sufficient information for a reader to determine the value of the program). Listed on the reverse side of this form are subjects which may serve as a guide for a descriptive abstract.

Revised 4/74

SHARE PROGRAM LIBRARY SUBMITTAL FORM

Subject Guide:

a. Purpose
b. Programming Language used
c. Version and modification level or release number
d. Field of application
e. Type of routine (main program, subroutine, etc.)
f. Specific description of machine requirements

ABSTRACT

The programs FMSPREV, ANINTP, and ARBINTP are intended to be used for terrestrial microwave radio interference coordination.

The FMSPREY program calculates the spectral density of an FDM-FM signal, and ANINTP calculates the interference between two analog, FDM-FM signals, and ARBINTP calculates the interference between one analog FDM-FM signal and another signal of arbitrary spectral density.

The documentations includes User's Manuals and limitations of the software.

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(Please attach additional pages if necessary)..........Total pages attached ____

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(17) Signature of Submitter and Date *Michael A. Pagones* *4-22-75*

(18) Signature of Installation Addressee ____

CARD DECK KEY

Deck #1 FMSPREV

PL/I (F) Source Deck
Sequence 40 through [redacted] in Columns 74-80
179 cards 1910

Deck #2 ANINTP

PL/I (F) Source Deck
Sequence 60.00 through 9200.00 in Columns 74-80
913 cards

Deck #3 ARBINTP

PL/I (F) Source Deck
Sequence 60.00 through 9500.00 in Columns 74-80
961 cards

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UNLABELED
80 BYTE SOURCE CODE RECORDS
BLOCKED AT 4000 BYTES.

FILE 1: FMSPREV SOURCE
FILE 2: ANINTP SOURCE
FILE 3: ARBINTP SOURCE

Bell Laboratories

subject: Computation of Analog FM Spectra

date: January 12, 1970

from: Leif Lundquist

ABSTRACT

A program has been written for the computation of analog FM spectra with a modulating signal of multichannel telephony. Comparison with available data show very good agreement. However, the program is limited to mean square phase deviations of less than 10.

Three choices of pre-emphais are available - a power series approximation, CCIR, and no pre-emphasis, but other baseband spectrum shapes can easily be included.

BELL TELEPHONE LABORATORIES
INCORPORATED

SUBJECT: Computation of Analog FM Spectra

DATE: January 12, 1970

FROM: Leif Lundquist

MEMORANDUM FOR FILE

1. Introduction

Over the past years many attempts to compute spectra of FM-FDM signals have been made. The greatest problem has always been to get numerical results.

The usual assumption is that the multiplex signal be approximated by a bandlimited Gaussian signal. The spectrum may then be written as a sum of n-order convolutions of the phase spectrum. But convolutions have always been time consuming. However, we can make use of the Fast Fourier Transform algorithm to perform the convolutions and this cuts down computation time considerably.

The program presented makes use of the FFT and a number of different spectra are computed.

2. Analysis

If we assume that v(t) is the RF signal, phase modulated by $\phi(t)$ then[1]

$$S_v(f_c+f) = e^{-R_\phi(0)}\left[\delta(f_c) + \sum_{n=1}^{\infty} \frac{1}{n!} S_\phi(f) \overset{n-1}{*} S_\phi(f)\right] \quad (1)$$

where

- f is frequency
- f_c is the carrier frequency
- S_ϕ is the spectral density of ϕ
- R_ϕ is the autocorrelation function of ϕ.

We assume $S_\phi(f)$ to extend from a bottom baseband frequency, FBOT, to a top baseband frequency FTOP. There are problems with convergence of equation (1) if FBOT = 0 and in the program this is not allowed. The program uses 64 data points to describe the positive portion of $S_\phi(f)$. The minimum FBOT therefore, is of the order of FTOP/64.

The necessary number of terms taken in equation (1) is a function of $R_\phi(0)$, i.e., the mean square phase deviation.

$$R_\phi(0) = \int_{-\infty}^{\infty} S_\phi(\omega)d\omega \qquad (2)$$

Equation (1) is usually obtained from $R_v(\tau)$ the average autocorrelation function of v:

$$R_v(\tau) = e^{-R_\phi(0) + R_\phi(\tau)} \qquad (3)$$

Writing $e^{R_\phi(\tau)}$ as a series we get

$$R_v(\tau) = e^{-R_\phi(0)} \cdot \sum_{n=0}^{\infty} \frac{(R_\phi(\tau))^n}{n!} \qquad (4)$$

Taking the Fourier transform of equation (4) we get equation (1).

Equation (4) can be used to give an estimate of how many terms are needed to get an accurate measure of the sideband energy. The first term represents the carrier energy $e^{-R_\phi(0)}$. Each consecutive term represents sideband energy and we can get the total contribution from each term by letting $\tau = 0$. The problem is then to determine how well an exponential $e^{R_\phi(0)}$ can be represented by a truncated power series.

Here we use 15 terms in the series and this allows us to use $0 \leq R_\phi(0) \leq 10$. When $R_\phi(0) = 10$, 95% of the sideband energy is contained in the 15 first terms.

For $R_\phi(0) > 10$ there are other methods for computing spectra, e.g., the Gaussian approximation.

3. Program

Figures 1-5 (attached) show a flowchart of FMSPCTR. The program is a PL-1 procedure written for the IBM 360 system. The IBM FFT subroutine is used. FFT is the Fast Fourier Transform procedure which is part of the OS 360 scientific subroutine package.

The input parameters to the program are in the order they should appear on the input cards:

SSYS: System name. Limited to five characters.

NTA: Number of talkers.

FTOP: Top baseband frequency in Hz.

FBOT: Bottom baseband frequency in Hz.

FRMS: RMS frequency deviation in Hz.

PRE: One of 'NONE', 'CCIR', and 'BELL'.

If PRE = 'BELL' the pre-emphasis is assumed to be of the form

$$A0 + A2\left(\frac{f}{FTOP}\right)^2 + A4\left(\frac{f}{FTOP}\right)^4 + A6\left(\frac{f}{FTOP}\right)^6$$

and the input data should continue after PRE with

A0

A2

A4

A6

If PRE = 'NONE' or 'CCIR', PRE is the last input datum.

In computing the baseband spectrum the program assumes a -16 dBm0 talker. Since the RMS frequency deviation is part of the input data, the talker power is of no consequence when computing the RF spectrum.

4. Results

The program has been checked out by comparing some of these spectra with the few that were available. There is excellent agreement. For larger phase deviations the Gaussian approximation agrees well with the computed spectra.

5. Acknowledgement

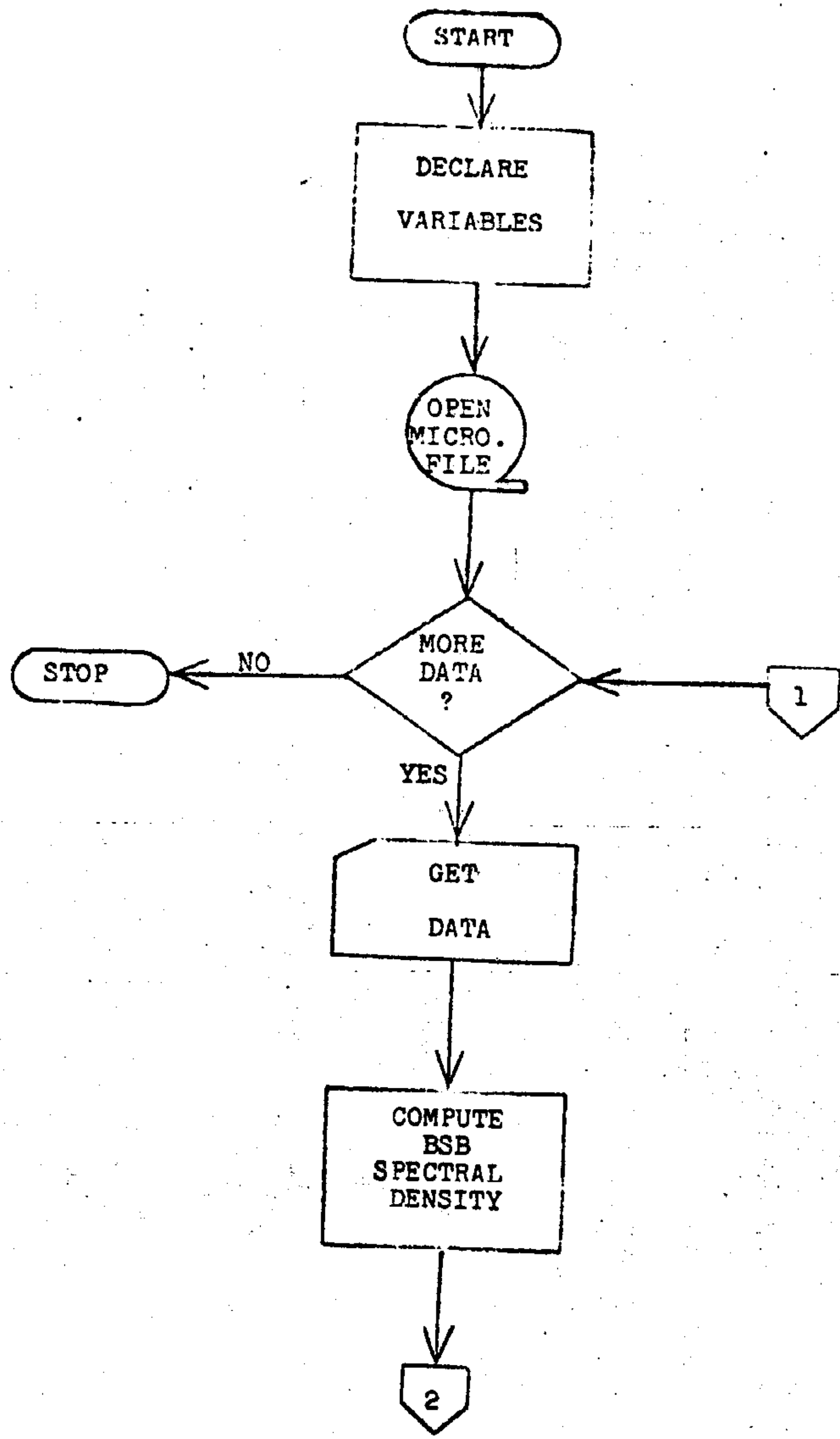
Many thanks to Shirley Geiger who provided invaluable assistance in communicating with the computer.

Leif Lundquist

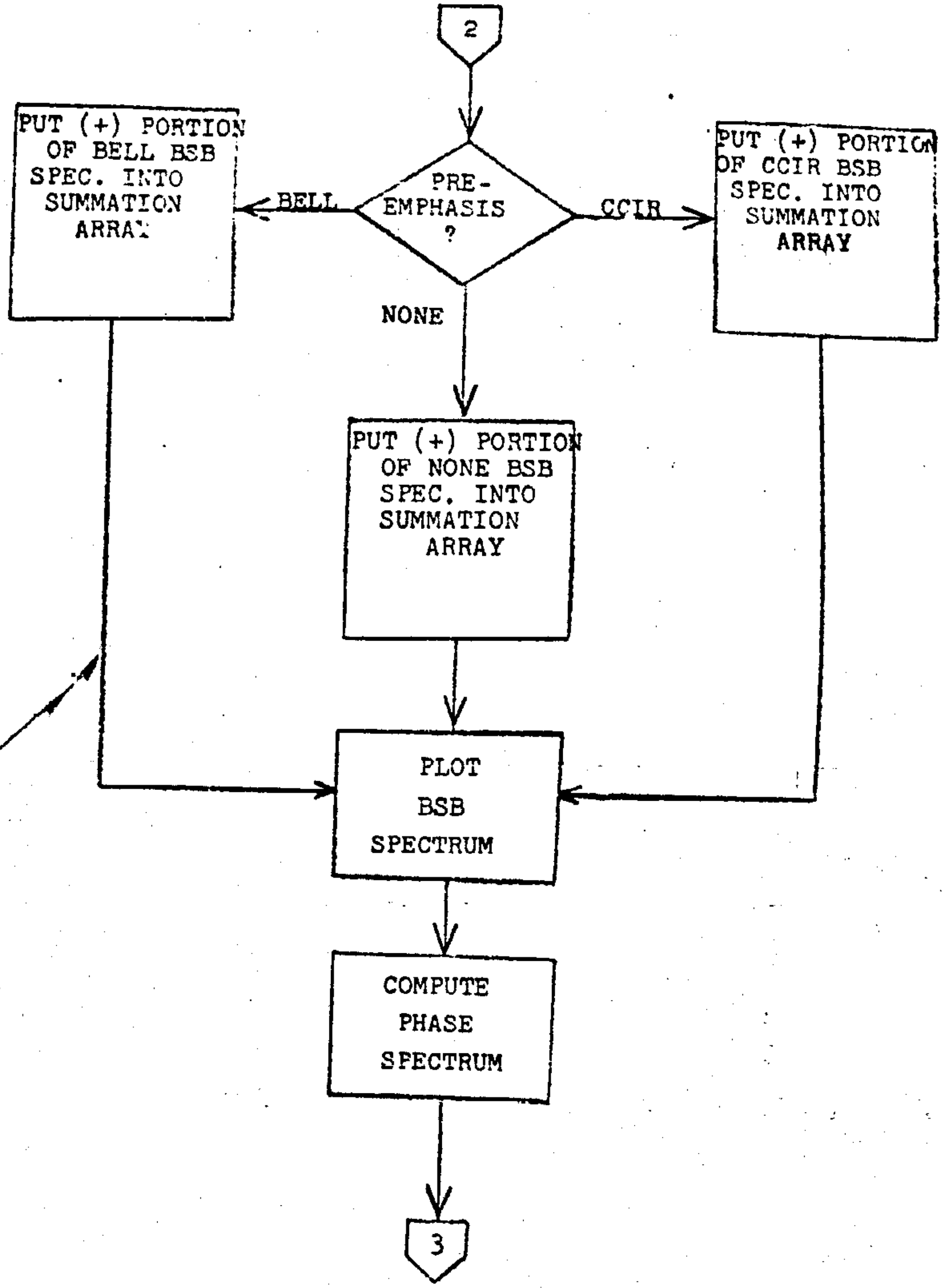
Atts.
References
Figures 1 through 5

REFERENCES

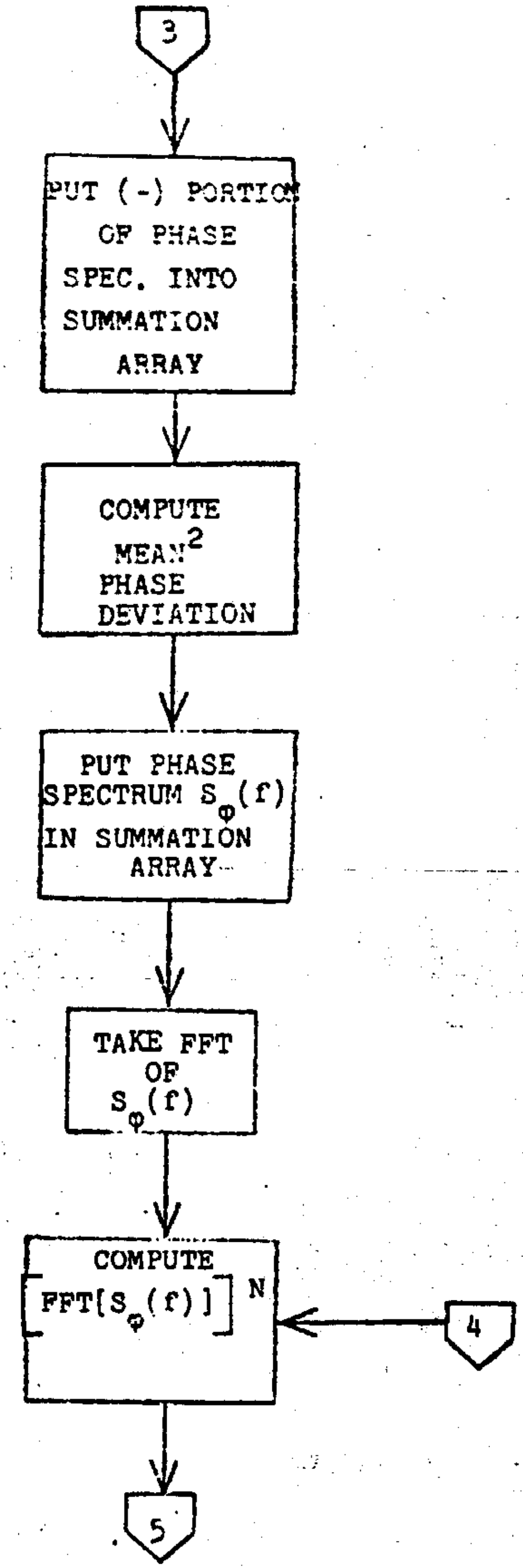
1. N. Abramson, "Bandwidth and Spectra of Phase-and-Frequency-Modulated Waves," IEEE Tran. on Com. Syst., Vol. CS-11, No. 4; December 1963.



ISSUE	ENGR / DRAWN	TITLE	BELL TELEPHONE LABORATORIES INCORPORATED
		FIGURE 1	



ISSUE	ENGR	TITLE	BELL TELEPHONE LABORATORIES INCORPORATED
	DRAWN	FIGURE 2	



ISSUE	ENGR	TITLE	BELL TELEPHONE LABORATORIES INCORPORATED
	DRAWN	FIGURE 3	

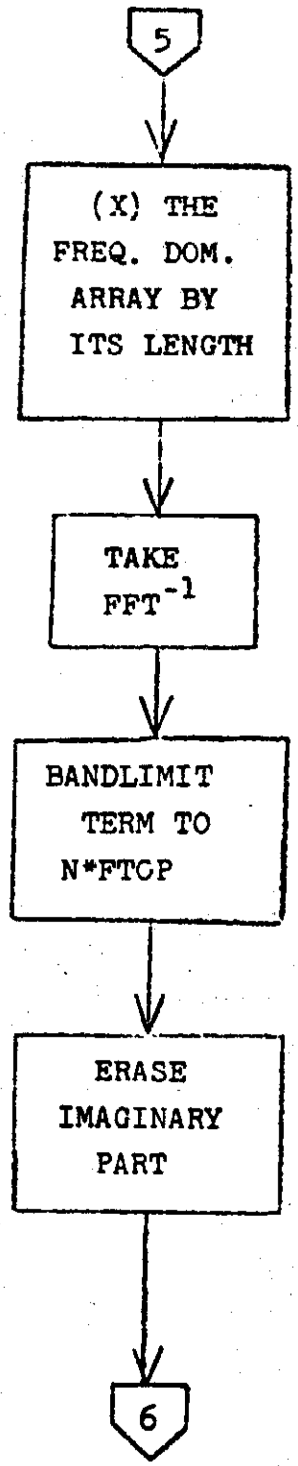
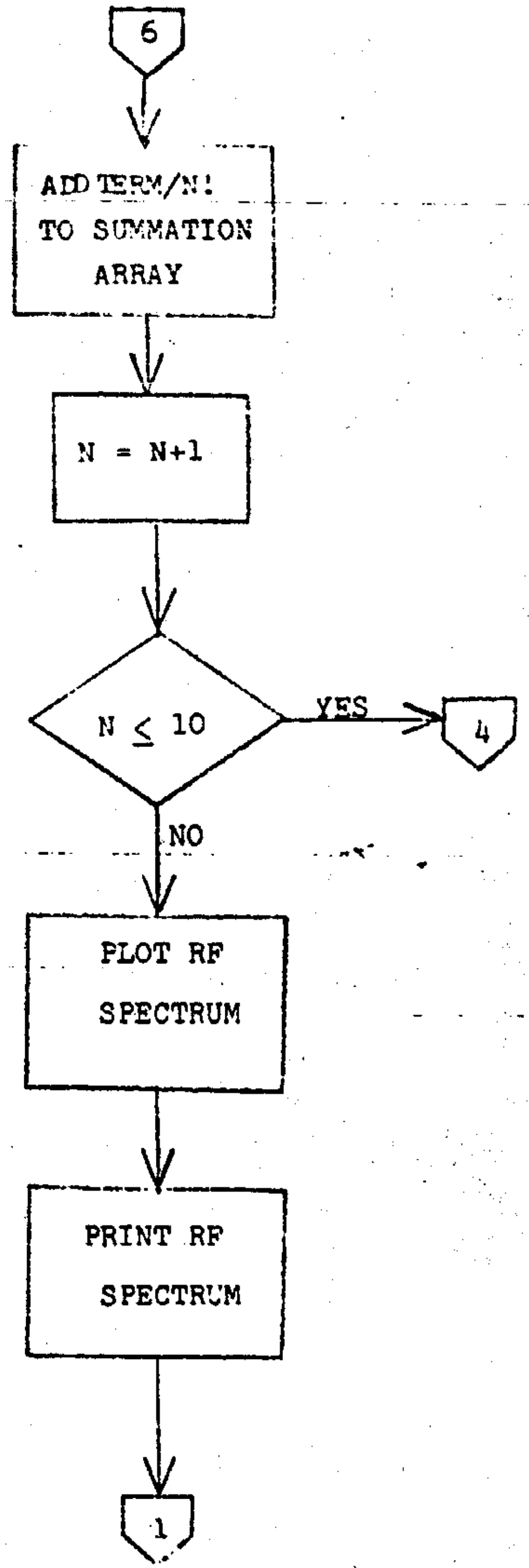

5
(X) THE FREQ. DOM. ARRAY BY ITS LENGTH
TAKE FFT-1
BANDLIMIT TERM TO N*FTOP
ERASE IMAGINARY PART
6

FIGURE 4



ISSUE | ENGR | DRAWN | TITLE

FIGURE 5

BELL TELEPHONE LABORATORIES

Bell Laboratories

subject: Analog FDM-FM Interference Program, ANINT. User's Manual

date: April 28, 1971

from: Sally L. Fennick
Shirley G. Lawrence
Leif Lundquist

ABSTRACT

This version of the interference computation program is written for usage by AT&T in their microwave coordination procedures. The programs compute necessary discrimination between two FDM-FM radio channels given the characteristics of each radio system.

MEMORANDUM FOR FILE

1. Introduction

The multitude of new microwave facilities going in all over the country is making the coordination between systems increasingly complicated. As a help in this process we have developed a program which computes the baseband noise due to interference of one analog system into another. This is the first program in a series planned to cover most common interference cases.

The theory behind this program has been developed in several memoranda and articles and we will not go into any detail here. The general idea is to convolve (beat) two RF spectra with each other and thus arriving at the baseband spectrum of the interference. The spectrum arrived at is compared with the baseband multiplex signal and, given the tolerable noise, the necessary RF discrimination is found. The heart of the program is subroutine FMSP which computes FM spectra given the spectrum of the modulating signal.

Filtering of the received signal is assumed when the two RF signals are nominally off frequency. The filter is a square bandlimiting filter of bandwidth 3.17 f_t + 9σ where f_t is the top baseband frequency and σ is the total rms frequency deviation. Appendix I shows a flowchart of the program.

2. Interpretation of Output

The output is designed to be largely self-explanatory, but there are several printing options so to be conclusive we list the various possible tables and messages with comments explaining what their functions are and what action the program takes.

1. Printing of system data
1a. A sentence showing which system is interfering into which and the frequency band.
1b. Nominal frequency difference
1c. Interference requirement
1d. Maximum frequency drift. This is computed based on the information about which frequency tolerances are operating in and what the frequency tolerances are. Tolerances equal to 0 will make the drift equal to 0.
1e. A table showing all the pertinent system data
2. The actual frequency difference used in the computations is printed. If the nominal frequency difference (FDNOM) is 0 then the actual frequency difference is set equal to the maximum drift, if not the actual frequency difference is equal to FDNOM.

3. If FDNOM = 0 there will be no filtering of the signals and a message is printed reminding the user of this. In this case most energy falls inband and filtering has very little effect. The program is speeded up because there is only one call for FMSP.
4. A message is printed in the main program when the frequency difference exceeds ten times the maximum of the top baseband frequencies for the two systems. Program execution will continue with the next set of data. The reason for this limitation is the limited length of the arrays holding the spectra. The frequency increment in each array is equal to 1/64th of the largest top baseband frequency and the total length of the complex RF arrays holding both negative and positive spectral components is 4096.
5. If FDNOM > 0 but the two systems are identical only one call to FMSP is made since both RF spectra are identical. The message "INDENTICAL RF SPECTRA" is printed.
6. If FDNOM > 0 we always apply RF bandlimiting to the total received signal. The bandwidth is computed in the program and printed.
7. Printing in Subrouting BSBSP

   If TH-1 preemphasis is used, the number of talkers should equal 1800, because the preemphasis is normalized to a frequency band corresponding to 1800 channels. A warning message is printed if the number of talkers does not equal 1800. Program execution will continue with the same set of data.
8. Printing in Subroutine FMSP

   If the deviation of an FM signal is large the RF spectrum is essentially Gaussian. The program computes the mean square phase deviation (RO) and if RO > 10 then a Gaussian approximation is used. The program prints RO and identifies the signal it is working on. A message saying the Gaussian approximating has been used, is printed and the rms frequency deviation is printed. Also a message saying that the carrier is equal to exp (-RO) is printed.

9. Printing of Output Data

9a. If the carrier beat falls below or above the baseband, a message is printed to that effect, and no carrier beat computations are made. If the drift is large and FDNOM is just larger than the top baseband frequency, we suggest running the program with FDNOM a little less than the top baseband frequency, since the drift might bring in the carrier beat to the top baseband channel.

9b. A message is printed showing how much the carrier beat noise is reduced by both carriers being modulated.

9c. Signal to noise ratio due to carrier beat and normalized to a carrier to interference ratio of unity (0 dB), is printed together with the corresponding amount of noise in dBrnC0.

9d. The necessary RF discrimination (C/I ratio) to generate the noise prescribed in the input data is printed together with a message that no burble has been accounted for. The factor mentioned in 9b is included and the C/I requirement should be increased if we cannot count on the effect of modulation. A burble factor, of course, allows us to decrease the C/I requirement.

9e. The interference at baseband is printed for each frequency increment falling within the baseband of the wanted signal. A table is printed showing baseband frequency normalized (to unity carrier to interference ratio) signal to interference ratio at baseband, corresponding noise in dBrnC0 and necessary RF discrimination (C/I ratio).

10. A message "END OF DATASET" is printed, and the program goes back for more data.
11. When all data sets are run a message "END OF PROGRAM" is printed.

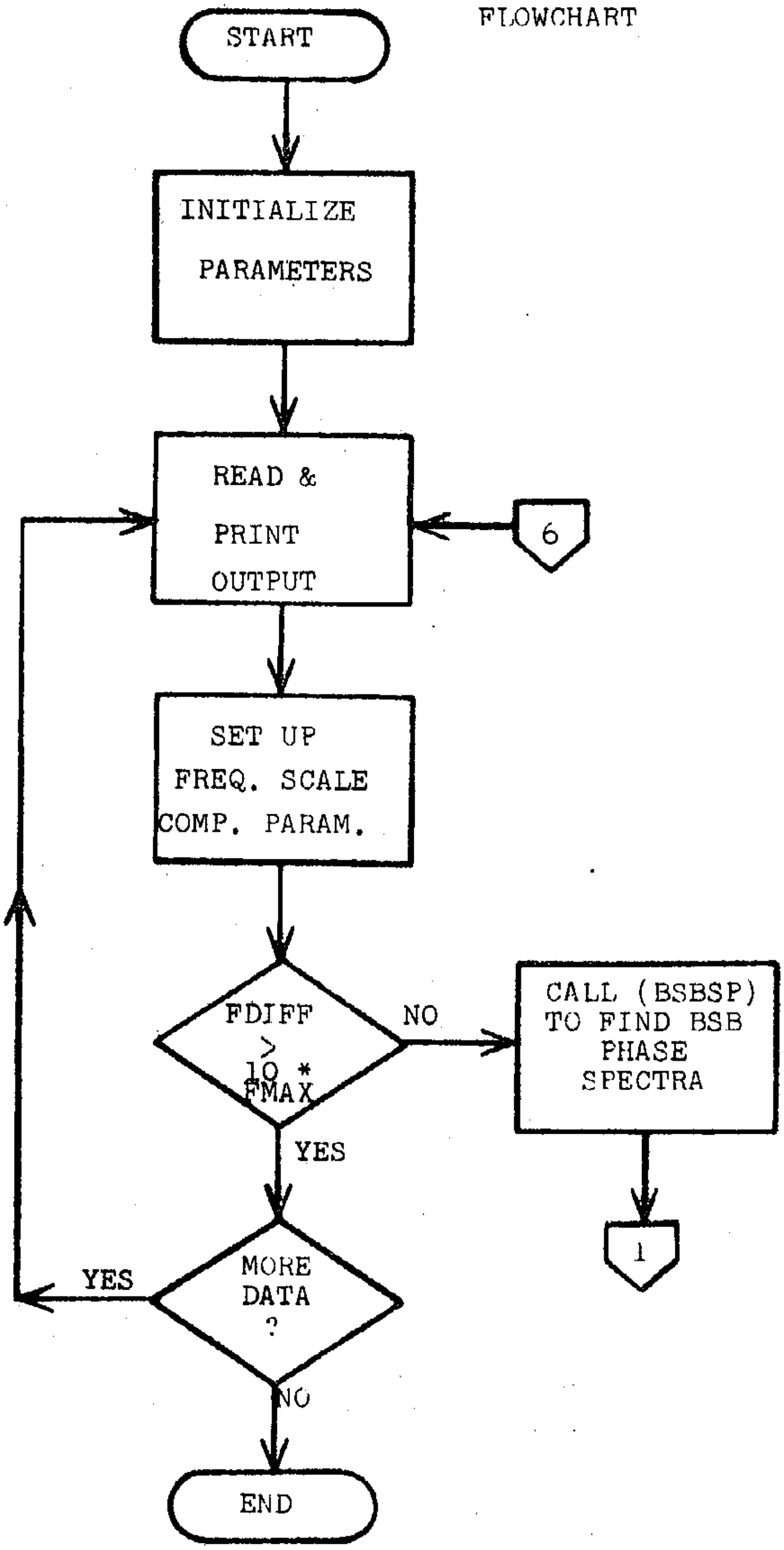
Sally L. Fennick

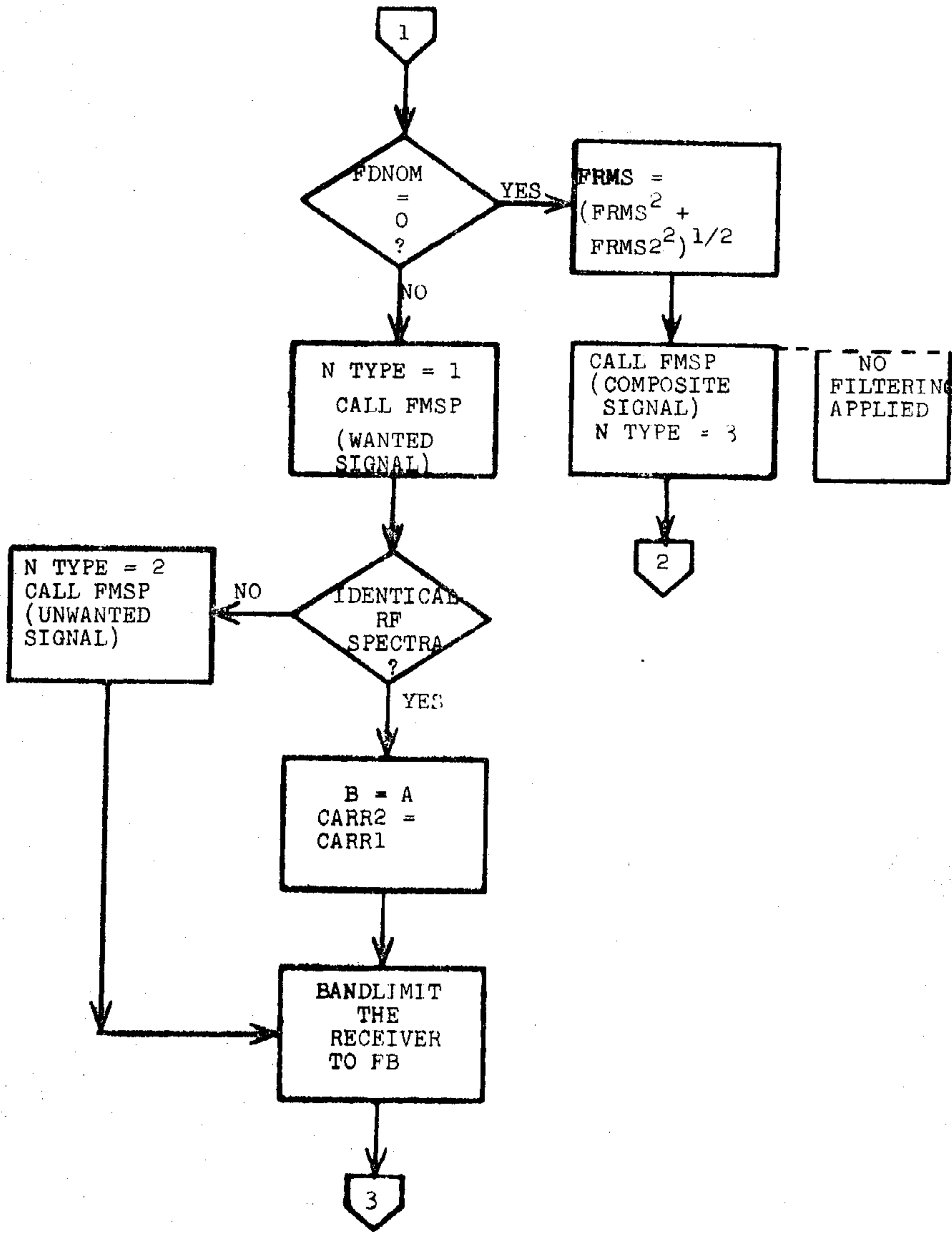
Shirley G. Lawrence

Leif Lundquist

Att.
Appendix I

APPENDIX I
FLOWCHART





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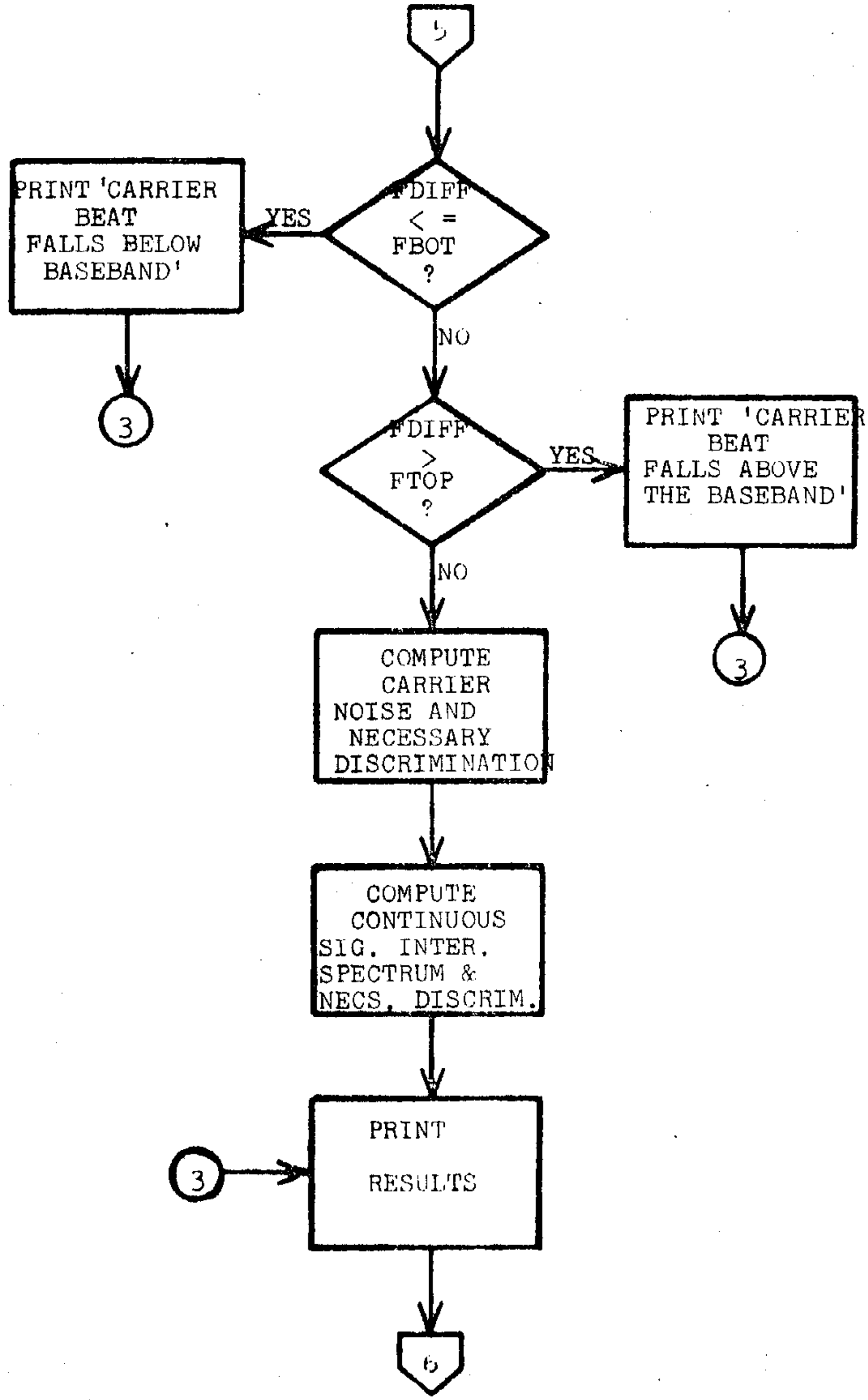
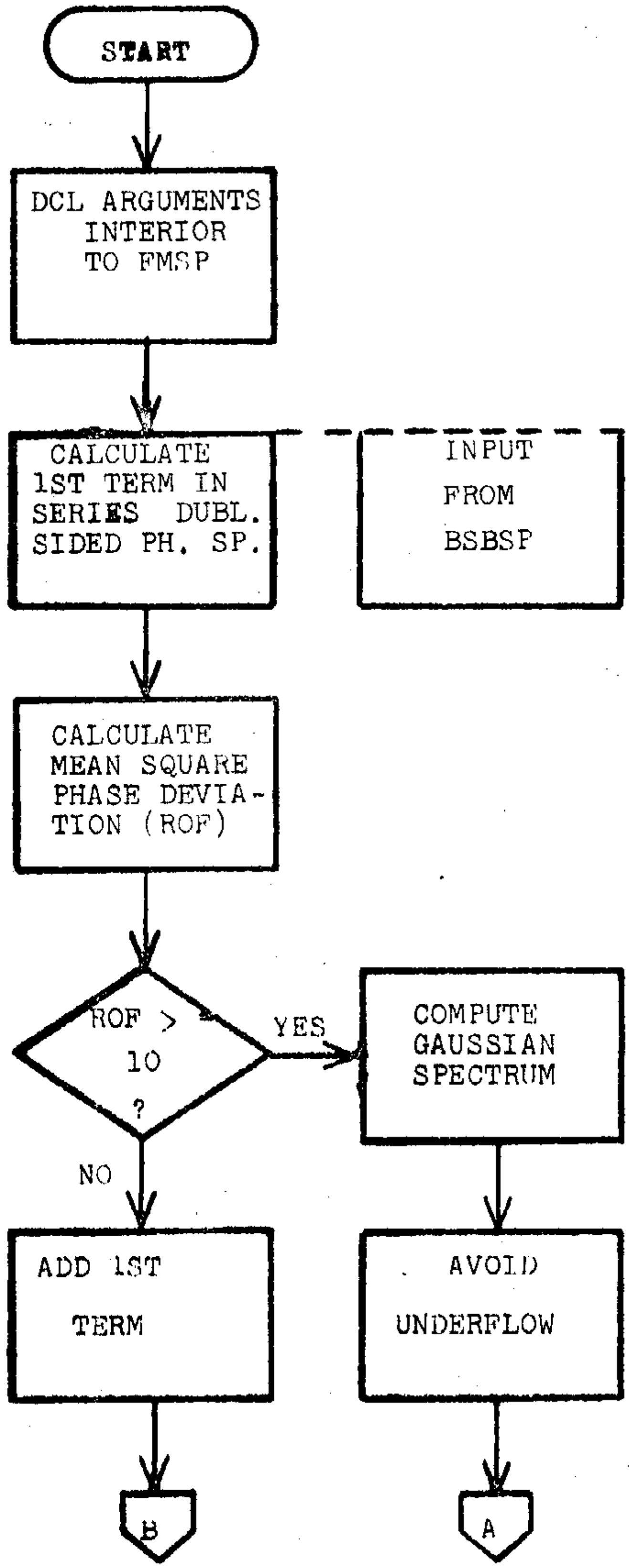
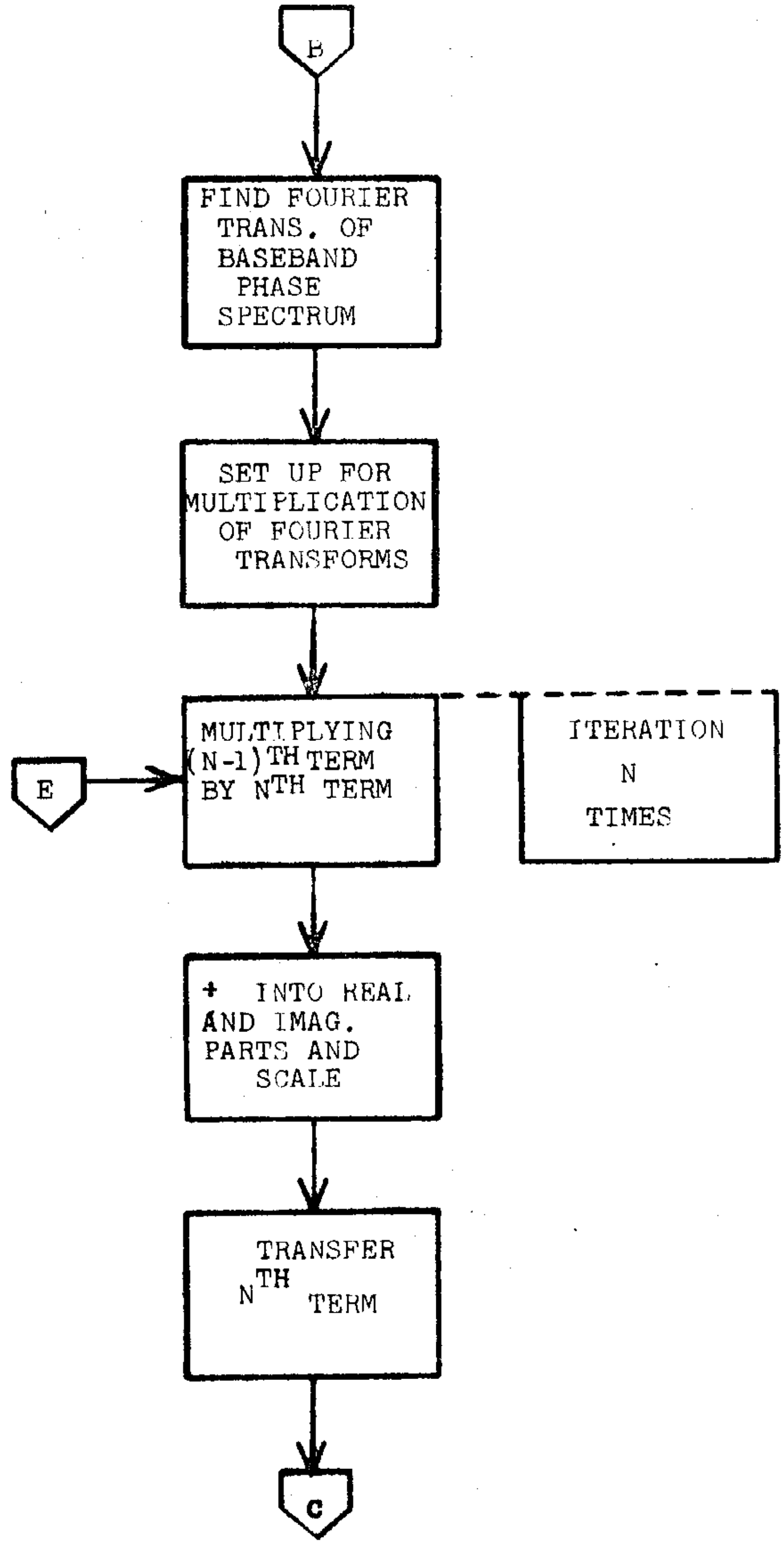

5
FDIFF < = FBOT ?
YES
PRINT 'CARRIER BEAT FALLS BELOW BASEBAND'
3
NO
FDIFF > FTOP ?
YES
PRINT 'CARRIER BEAT FALLS ABOVE THE BASEBAND'
3
NO
COMPUTE CARRIER NOISE AND NECESSARY DISCRIMINATION
COMPUTE CONTINUOUS SIG. INTER. SPECTRUM & NECS. DISCRIM.
3
PRINT RESULTS
6

SHEET 5

RF SPECTRUM (FMSP)





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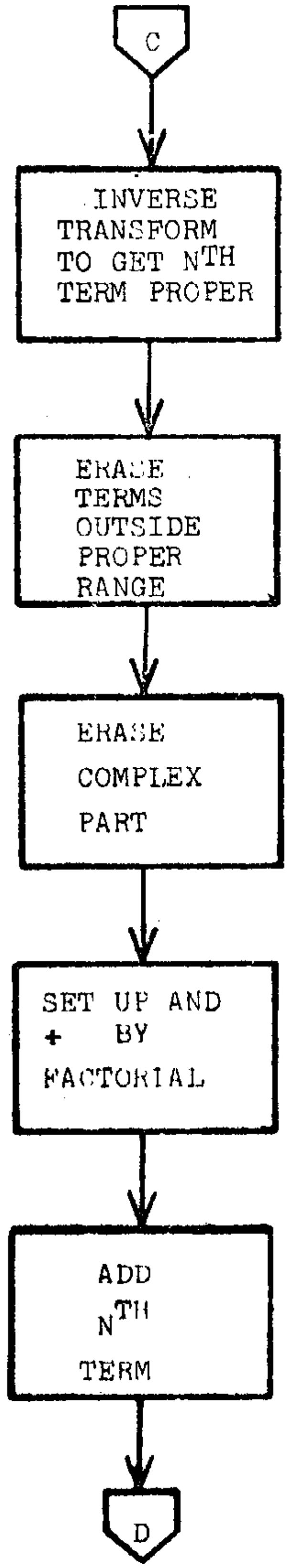
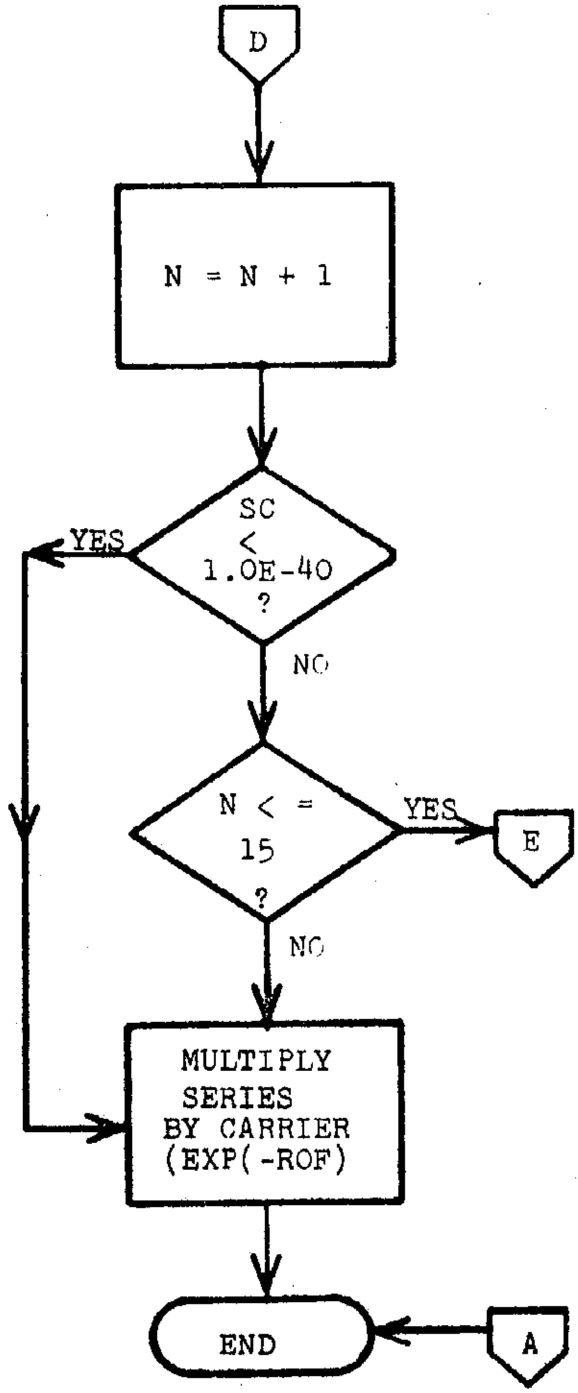
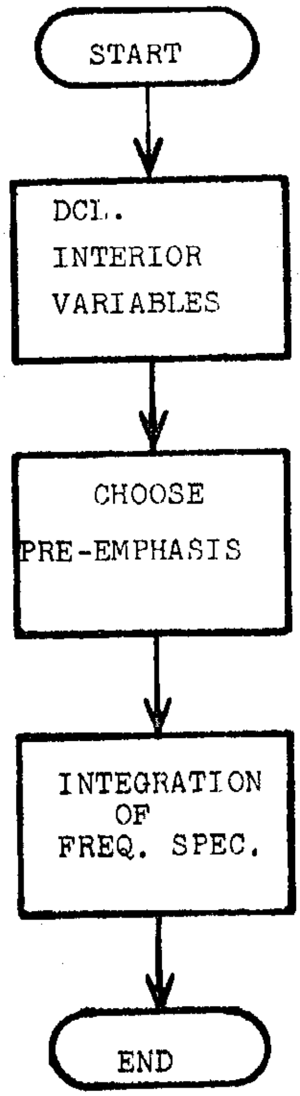
NO. OF SHEETS PER SET

SHEET 7


C
INVERSE TRANSFORM TO GET N^TH TERM PROPER
ERASE TERMS OUTSIDE PROPER RANGE
ERASE COMPLEX PART
SET UP AND + BY FACTORIAL
ADD N^TH TERM
D


D
N = N + 1
SC < 1.0E-40 ?
YES
NO
N < = 15 ?
YES
E
NO
MULTIPLY SERIES BY CARRIER (EXP(-ROF)
END
A

BASEBAND PHASE SPECTRA (BSBSP)



Bell Laboratories

subject: ARBINTP - Program to Compute Interference Noise in FDMFM Systems

date: May 24, 1971

from: Leif Lundquist

ABSTRACT

ARBINTP computes the baseband interference noise for the case when a signal of known but arbitrary shape is interfering into an analog FDMFM system. Given the noise requirement of the system, ARBINTP also prints the necessary RF discrimination.

Bell Laboratories

subject: ARBINTP - Program to Compute Interference Noise in FDMFM Systems

date: May 24, [illegible]

from: Leif Lundquist

MEMORANDUM FOR FILE

1. Computation Method

Over the past years several programs to compute interference noise between radio systems have been written. This effort culminated with the ANalog INTerference program written for use by AT&T in their microwave coordination work.

In ANINT the method of computation is principally to compute the two RF spectra and convolve them to get the interference baseband spectrum. ARBINTP is a modified version of ANINTP (P stands for PL/1 version). The spectrum of the wanted analog signal is computed as in ANINT, whereas the RF spectrum of the unwanted signal is supplied by the user. This involves principally two changes. The first is convolution of spectra is always performed, even for systems that are nominally co-channel. RF filtering as in ANINT is always applied, and the frequency difference is always assumed to be the nominal frequency difference supplied by the user.

The second change is in the convolution. The spectrum of the wanted signal is characterized by a discrete part and a continuous part. The convolution therefore gets a bit more involved and the frequency shifting has to be done separately for each contributor to the final interference spectrum.

The continuous spectra used in the program are sampled every 1/64th of the top baseband frequency (FTOP) of the wanted signal. The input data of the unwanted spectrum can be defined at any frequencies less than 20*FTOP away from the wanted carrier. The program will interpolate at multiples of FTOP/64, between the lowest and highest given frequency, using the input data. For instance if the user wishes to find the interference from a flat spectrum 90 dB below total power/Hz between -10 MHz and +10 MHz relative to the unwanted carrier frequency, the two pairs -10, -90 and 10, -90 can be fed into the program. The program will then interpolate between -10 MHz and +10 MHz and set all points in between equal to 10^{-9} relative to total power/Hz. Everything outside this range is set equal to 0.

A listing of ARBINTP is included in Appendix I. I believe some familiarity with ANINT together with the comments in the listing should be sufficient to understand how the program works. As in ANINT we assume a minimum of 10 dB carrier to interference ratio.

2. Input Data

Parameters for ARBINTP are:

Card #		Units	Program Variable Name
1	Frequency band	GHz	BAND
2	Interference requirement	DBRNCO	REQ
	Nominal frequency dif.	MHz	FDNOM
3	System 1 name (wanted)	Character	SSYS
	Number of talkers	Integer	NTA
	Top Baseband Frequency	MHz	FTOP
	Bottom Baseband Frequency	MHz	FBOT
	Frequency deviation	MHz	FRMS
	Frequency tolerance	Per cent	TOL1
	Pre-emphasis	Character*	PRE

* Choice of 'CCIR', 'BELL', 'NONE', 'TH-1'.

Card #		Units	Program Variable Name
3A	Optional, required if and only if pre-emphasis (PRE) is 'BELL'. Pre-emphasis coefficients		A0 A2 A4 A6
4	System 2 name (unwanted)	Character	SSYS2
	Frequency tolerance	Per cent	TOL2
	No. of discrete data	Integer	NDIS
	No. of continuous data	Integer	NCON
5	Frequency	MHz	FRDIS(1)
	Discrete power	dB rel. total power	LEVDIS(1)
	⋮		
4 + NDIS	Frequency	MHz	FRDIS(NDIS)
	Discrete power	dB rel. total power	LEVDIS(NDIS)
4 + NDIS + 1	Frequency	MHz	FRCON(1)
	Continuous power density	dB rel. total power/Hz	LEVCON(1)
	⋮		
4 + NDIS + NCON	Frequency	MHz	FRCON(NCON)
	Continuous power density	dB rel. total power/Hz	LEVCON(NCON)

The frequencies for both discrete and continuous data should be ordered from smallest to largest, in order to make the interpolation work.

3. Output Data

The format is the same as for ANINTP with the exception of the discrete components, which in ARBINTP are printed in a table because we may have many.

Leif Lundquist

LEIF LUNDQUIST

Att.
Additional References
Appendix I