

# fftpack5

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## NAME

FFTPACK5 - a FORTRAN library of fast Fourier transforms

## SYNOPSIS

### Complex Transform Routines

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<a href="#"><u>CFFT1I</u></a>	1D complex initialization
<a href="#"><u>CFFT1B</u></a>	1D complex backward
<a href="#"><u>CFFT1F</u></a>	1D complex forward
<a href="#"><u>CFFT2I</u></a>	2D complex initialization
<a href="#"><u>CFFT2B</u></a>	2D complex backward
<a href="#"><u>CFFT2F</u></a>	2D complex forward
<a href="#"><u>CFFTMI</u></a>	multiple complex initialization
<a href="#"><u>CFFTMB</u></a>	multiple complex backward
<a href="#"><u>CFFTMF</u></a>	multiple complex forward

### Real Transform Routines

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<a href="#"><u>RFFT1I</u></a>	1D real initialization
<a href="#"><u>RFFT1B</u></a>	1D real backward
<a href="#"><u>RFFT1F</u></a>	1D real forward
<a href="#"><u>RFFT2I</u></a>	2D real initialization
<a href="#"><u>RFFT2B</u></a>	2D real backward
<a href="#"><u>RFFT2F</u></a>	2D real forward

<a href="#">RFFTMI</a>	multiple real initialization
<a href="#">RFFTMB</a>	multiple real backward
<a href="#">RFTMF</a>	multiple real forward

## Real Cosine Transform Routines

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<a href="#">COST1I</a>	1D real cosine initialization
<a href="#">COST1B</a>	1D real cosine backward
<a href="#">COST1F</a>	1D real cosine forward
<a href="#">COSTMI</a>	multiple real cosine initialization
<a href="#">COSTMB</a>	multiple real cosine backward
<a href="#">COSTMF</a>	multiple real cosine forward

## Real Sine Transform Routines

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<a href="#">SINT1I</a>	1D real sine initialization
<a href="#">SINT1B</a>	1D real sine backward
<a href="#">SINT1F</a>	1D real sine forward
<a href="#">SINTMI</a>	multiple real sine initialization
<a href="#">SINTMB</a>	multiple real sine backward
<a href="#">SINTMF</a>	multiple real sine forward

## Real Quarter-Cosine Transform Routines

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<a href="#">COSQ1I</a>	1D real quarter-cosine initialization
<a href="#">COSQ1B</a>	1D real quarter-cosine backward
<a href="#">COSQ1F</a>	1D real quarter-cosine forward
<a href="#">COSQMI</a>	multiple real quarter-cosine initialization
<a href="#">COSQMB</a>	multiple real quarter-cosine backward
<a href="#">COSQMF</a>	multiple real quarter-cosine forward

## Real Quarter-Sine Transform Routines

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<a href="#">SINQ1I</a>	1D real quarter-sine initialization
<a href="#">SINQ1B</a>	1D real quarter-sine backward
<a href="#">SINQ1F</a>	1D real quarter-sine forward
<a href="#">SINQMI</a>	multiple real quarter-sine initialization
<a href="#">SINQMB</a>	multiple real quarter-sine backward
<a href="#">SINQMF</a>	multiple real quarter-sine forward

## DESCRIPTION

Library FFTPACK5 contains 1D, 2D, and multiple fast Fourier subroutines, written in Fortran 77, for transforming real and complex data, real even and odd wave data, and real even and odd quarter-wave data. All of the FFTPACK5 routines listed above are grouped in triplets e.g. {CFFT1I, CFFT1F, CFFT1B}. The suffix *I* denotes initialize, *F* denotes forward (as in forward transform) and *B* denotes backward. In an application program, before calling *B* or *F* routines for the first time, or before calling them with a different length, users must initialize an array by calling the *I* routine of the appropriate pair or triplet. Note that *I* routines need not be called each time before a B or F routine is called.

All of the transform routines in FFTPACK5 are normalized.

Error messages are written to unit 6 by routine XERFFT. The standard version of XERFFT issues an error message and halts execution, so that no FFTPACK routine will return to the calling program with error return IER different than zero. Users may consider modifying the STOP statement in order to call system-specific exception-handling facilities.

FFTPACK5 is written in standard Fortran 77 except for several instances where arrays of type REAL or COMPLEX are passed to a subroutine and used as a different type.

## References

- (1) Vectorizing the Fast Fourier Transforms, by Paul Swarztrauber, Parallel Computations, G. Rodrigue, ed., Academic Press, New York 1982.
  - (2) Fast Fourier Transforms Algorithms for Vector Computers, by Paul Swarztrauber, Parallel Computing, (1984) pp.45-63.
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# cfft1i

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## NAME

CFFT1I - initialization routine for CFFT1B and CFFT1F

## SYNOPSIS

```
SUBROUTINE CFFT1I (N, WSAVE, LENSAB, IER)
INTEGER          N, LENSAB, IER
REAL             WSAVE(LENSAB)
```

## DESCRIPTION

FFTPACK 5.0 subroutine CFFT1I initializes array WSAVE for use in its companion routines CFFT1B and CFFT1F. Routine CFFT1I must be called before the first call to CFFT1B or CFFT1F, and after whenever the value of integer N changes.

### Input Arguments

**N** Integer length of the sequence to be transformed. The transform is most efficient when N is a product of small primes.

**LENSAB** Integer dimension of WSAVE array. LENSAB must be at least  $2*N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

### Output Arguments

**WSAVE** Real work array with dimension LENSAB, containing the prime factors of N and also containing certain trigonometric values which will be used in routines CFFT1B or CFFT1F.

IER       = 0 successful exit  
          = 2 input parameter LENSAB not big enough

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# cfft1b

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## NAME

CFFT1B - complex backward fast Fourier transform

## SYNOPSIS

```
SUBROUTINE CFFT1B (N, INC, C, LENC, WSAVE, LENSAB,  
1                  WORK, LENWRK, IER)
```

```
INTEGER      N, INC, LENC, LENSAB, LENWRK, IER  
COMPLEX      C(LENC)  
REAL         WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine CFFT1B computes the one-dimensional Fourier transform of a single periodic sequence within a complex array. This transform is referred to as the backward transform or Fourier synthesis, transforming the sequence from spectral to physical space.

This transform is normalized since a call to CFFT1B followed by a call to CFFT1F (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

N	Integer length of the sequence to be transformed. The transform is most efficient when N is a product of small primes.
INC	Integer increment between the locations, in array C, of two consecutive elements within the sequence to be transformed.

C           Complex array of length LENC containing the sequence to be transformed.

LENC       Integer dimension of C array. LENC must be at least  $INC*(N-1) + 1$ .

WSAVE      Real work array with dimension LENSAB. WSAVE's contents must be initialized with a call to subroutine CFFT1I before the first call to routine CFFT1F or CFFT1B for a given transform length N. WSAVE's contents may be re-used for subsequent calls to CFFT1F and CFFT1B with the same N.

LENSAB     Integer dimension of WSAVE array. LENSAB must be at least  $2*N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

WORK       Real work array of dimension LENWRK.

LENWRK     Integer dimension of WORK array. LENWRK must be at least  $2*N$ .

#### Output Arguments

C           For index  $J*INC+1$  where  $J=0, \dots, N-1$ ,

$$C(J*INC+1) =$$

$$\sum_{K=0}^{N-1} C(K*INC+1) * \text{EXP}(I * J * K * 2 * \text{PI} / N)$$

where  $I = \text{SQRT}(-1)$ .

At other indices, the output value of C does not differ from input.

IER        = 0 successful exit  
             = 1 input parameter LENC    not big enough  
             = 2 input parameter LENSAB not big enough  
             = 3 input parameter LENWRK not big enough

= 20 input error returned by lower level routine

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# cfft1f

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## NAME

CFFT1F - complex forward fast Fourier transform

## SYNOPSIS

```
SUBROUTINE CFFT1F (N, INC, C, LENC, WSAVE, LENSAB,  
1                  WORK, LENWRK, IER)
```

```
INTEGER      N, INC, LENC, LENSAB, LENWRK, IER  
COMPLEX      C(LENC)  
REAL         WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine CFFT1F computes the one-dimensional Fourier transform of a single periodic sequence within a complex array. This transform is referred to as the forward transform or Fourier analysis, transforming the sequence from physical to spectral space.

This transform is normalized since a call to CFFT1F followed by a call to CFFT1B (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

N	Integer length of the sequence to be transformed. The transform is most efficient when N is a product of small primes.
INC	Integer increment between the locations, in array C, of two consecutive elements within the sequence to be transformed.

C           Complex array of length LENC containing the sequence to be transformed.

LENC       Integer dimension of C array. LENC must be at least  $INC*(N-1) + 1$ .

WSAVE      Real work array with dimension LENSAB. WSAVE's contents must be initialized with a call to subroutine CFFT1I before the first call to routine CFFT1F or CFFT1B for a given transform length N. WSAVE's contents may be re-used for subsequent calls to CFFT1F and CFFT1B with the same N.

LENSAB     Integer dimension of WSAVE array. LENSAB must be at least  $2*N + INT(LOG(REAL(N))) + 4$ .

WORK       Real work array of dimension LENWRK.

LENWRK     Integer dimension of WORK array. LENWRK must be at least  $2*N$ .

#### Output Arguments

C           For index  $J*INC+1$  where  $J=0, \dots, N-1$  (that is, for the Jth element of the sequence),

$$C(J*INC+1) =$$

$$\sum_{K=0}^{N-1} C(K*INC+1) * \exp(-I * J * K * 2 * \pi / N)$$

where  $I = \text{SQRT}(-1)$ .

At other indices, the output value of C does not differ from input.

IER        = 0 successful exit  
             = 1 input parameter LENC    not big enough  
             = 2 input parameter LENSAB not big enough  
             = 3 input parameter LENWRK not big enough  
             = 20 input error returned by lower level routine

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# cfft2i

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## NAME

CFFT2I - initialization routine for CFFT2B, CFFT2F

## SYNOPSIS

```
SUBROUTINE CFFT2I (L, M, WSAVE, LENSAB, IER)
```

```
INTEGER      L, M, LENSAB, IER  
REAL         WSAVE(LENSAB)
```

## DESCRIPTION

FFTPACK 5.0 routine CFFT2I initializes real array WSAVE for use in its companion routines CFFT2F and CFFT2B for computing two-dimensional fast Fourier transforms of complex data. Prime factorizations of L and M, together with tabulations of the trigonometric functions, are computed and stored in array WSAVE.

### Input Arguments

- |        |   |
|--------|---|
| L      | Integer number of elements to be transformed in the first dimension. The transform is most efficient when L is a product of small primes.                   |
| M      | Integer number of elements to be transformed in the second dimension. The transform is most efficient when M is a product of small primes.                  |
| LENSAB | Integer dimension of WSAVE array. LENSAB must be at least $2*(L+M) + \text{INT}(\text{LOG}(\text{REAL}(L))) + \text{INT}(\text{LOG}(\text{REAL}(M))) + 8$ . |

## Output Arguments

- WSAVE     Real work array with dimension LENSAB, containing the prime factors of L and M, and also containing certain trigonometric values which will be used in routines CFFT2B or CFFT2F.
- WSAVE     Real work array with dimension LENSAB. The WSAVE array must be initialized with a call to subroutine CFFT2I before the first call to CFFT2B or CFFT2F, and thereafter whenever the values of L, M or the contents of array WSAVE change. Using different WSAVE arrays for different transform lengths or types in the same program may reduce computation costs because the array contents can be re-used.
- IER        Integer error return  
          = 0 successful exit  
          = 2 input parameter LENSAB not big enough  
          = 20 input error returned by lower level routine
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# cfft2b

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## NAME

CFFT2B - complex, two-dimensional backward fast Fourier transform

## SYNOPSIS

```
SUBROUTINE CFFT2B (LDIM, L, M, C, WSAVE, LENSAB,  
1                  WORK, LENWRK, IER)
```

```
INTEGER      L, M, LDIM, LENSAB, LENWRK, IER  
COMPLEX      C(LDIM,M)  
REAL         WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine CFFT2B computes the two-dimensional discrete Fourier transform of a complex periodic array. This transform is known as the backward transform or Fourier synthesis, transforming from spectral to physical space.

Routine CFFT2B is normalized, in that a call to CFFT2B followed by a call to CFFT2F (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

**LDIM**      Integer first dimension of two-dimensional complex array C.

**L**          Integer number of elements to be transformed in the first dimension of the two-dimensional complex array C. The value of L must be less than or equal to that of LDIM. The transform is most efficient when L is a product of small primes.

**M** Integer number of elements to be transformed in the second dimension of the two-dimensional complex array C. The transform is most efficient when M is a product of small primes.

**C** Complex array of two dimensions containing the (L,M) subarray to be transformed. C's first dimension is LDIM, its second dimension must be at least M.

**WSAVE** Real work array with dimension LENSAB. WSAVE's contents must be initialized with a call to subroutine CFFT2I before the first call to routine CFFT2F or CFFT2B with transform lengths L and M. WSAVE's contents may be re-used for subsequent calls to CFFT2F and CFFT2B with the same transform lengths L and M.

**LENSAB** Integer dimension of WSAVE array. LENSAB must be at least  $2*(L+M) + \text{INT}(\text{LOG}(\text{REAL}(L))) + \text{INT}(\text{LOG}(\text{REAL}(M))) + 8$ .

**WORK** Real work array.

**LENWRK** Integer dimension of WORK array. LENWRK must be at least  $2*L*M$ .

## Output Arguments

**C** Complex output array. For purposes of exposition, assume the index ranges of array C are defined by  $C(0:L-1,0:M-1)$ .

For  $I=0, \dots, L-1$  and  $J=0, \dots, M-1$ , the  $C(I,J)$ 's are given in the traditional aliased form by

$$C(I,J) = \sum_{L1=0}^{L-1} \sum_{M1=0}^{M-1} C(L1,M1) * \exp(\sqrt{-1} * 2 * \pi * (I * L1 / L + J * M1 / M))$$

And in unaliased form, the  $C(I,J)$ 's are given by

$$C(I,J) = \sum_{L1=LS}^{LF} \sum_{M1=MS}^{MF} C(L1,M1,K1) * \\ L1=LS \quad M1=MS$$

$$\text{EXP}(\text{SQRT}(-1)*2*\text{PI}*(I*L1/L + J*M1/M))$$

where

$$\begin{aligned} LS &= -L/2 & \text{and } LF &= L/2-1 & \text{if } L \text{ is even;} \\ LS &= -(L-1)/2 & \text{and } LF &= (L-1)/2 & \text{if } L \text{ is odd;} \\ MS &= -M/2 & \text{and } MF &= M/2-1 & \text{if } M \text{ is even;} \\ MS &= -(M-1)/2 & \text{and } MF &= (M-1)/2 & \text{if } M \text{ is odd;} \end{aligned}$$

and

$$\begin{aligned} C(L1,M1) &= C(L1+L,M1) & \text{if } L1 \text{ is zero or negative;} \\ C(L1,M1) &= C(L1,M1+M) & \text{if } M1 \text{ is zero or negative;} \end{aligned}$$

The two forms give different results when used to interpolate between elements of the sequence.

IER      Integer error return  
= 0    successful exit  
= 2    input parameter LENSAB not big enough  
= 3    input parameter LENWRK not big enough  
= 5    input parameter L > LDIM  
= 20   input error returned by lower level routine

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# cfft2f

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## NAME

CFFT2F - complex, two-dimensional forward fast Fourier transform

## SYNOPSIS

```
SUBROUTINE CFFT2F (LDIM, L, M, C, WSAVE, LENSAB,  
1                  WORK, LENWRK, IER)
```

```
INTEGER      L, M, LDIM, LENSAB, LENWRK, IER  
COMPLEX      C(LDIM,M)  
REAL         WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine CFFT2F computes the two-dimensional discrete Fourier transform of a complex periodic array. This transform is known as the forward transform or Fourier analysis, transforming from physical to spectral space.

Routine CFFT2F is normalized, in that a call to CFFT2F followed by a call to CFFT2B (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

**LDIM**      Integer first dimension of two-dimensional complex array C.

**L**          Integer number of elements to be transformed in the first

dimension of the two-dimensional complex array C. The value of L must be less than or equal to that of LDIM. The transform is most efficient when L is a product of small primes.

- M Integer number of elements to be transformed in the second dimension of the two-dimensional complex array C. The transform is most efficient when M is a product of small primes.
- C Complex array of two dimensions containing the (L,M) subarray to be transformed. C's first dimension is LDIM, its second dimension must be at least M.
- WSAVE Real work array with dimension LENSAB. WSAVE's contents must be initialized with a call to subroutine CFFT2I before the first call to routine CFFT2F or CFFT2B with transform lengths L and M. WSAVE's contents may be re-used for subsequent calls to CFFT2F and CFFT2B having those same transform lengths.
- LENSAB Integer dimension of WSAVE array. LENSAB must be at least  $2*(L+M) + \text{INT}(\text{LOG}(\text{REAL}(L))) + \text{INT}(\text{LOG}(\text{REAL}(M))) + 8$ .
- WORK Real work array.
- LENWRK Integer dimension of WORK array. LENWRK must be at least  $2*L*M$ .

#### Output Arguments

- C Complex output array. For purposes of exposition, assume the index ranges of array C are defined by  $C(0:L-1,0:M-1)$ .

For  $I=0, \dots, L-1$  and  $J=0, \dots, M-1$ , the  $C(I,J)$ 's are given in the traditional aliased form by

$$C(I,J) = \frac{1}{(L*M)} \sum_{L1=0}^{L-1} \sum_{M1=0}^{M-1} C(L1,M1) * \exp(-\sqrt{-1} * 2 * \pi * (I * L1 / L + J * M1 / M))$$

And in unaliased form, the  $C(I,J)$ 's are given by

$$C(I,J) = \frac{1}{(L*M)} \sum_{L1=LS}^{LF} \sum_{M1=MS}^{MF} C(L1,M1) * \exp(-\sqrt{-1} * 2 * \pi * (I * L1 / L + J * M1 / M))$$

where

$LS = -L/2$       and  $LF = L/2 - 1$       if  $L$  is even;  
 $LS = -(L-1)/2$  and  $LF = (L-1)/2$       if  $L$  is odd;  
 $MS = -M/2$       and  $MF = M/2 - 1$       if  $M$  is even;  
 $MS = -(M-1)/2$  and  $MF = (M-1)/2$       if  $M$  is odd;

and

$C(L1,M1) = C(L1+L,M1)$  if  $L1$  is zero or negative;  
 $C(L1,M1) = C(L1,M1+M)$  if  $M1$  is zero or negative;

The two forms give different results when used to interpolate between elements of the sequence.

IER      Integer error return  
 = 0      successful exit  
 = 2      input parameter LENSAB not big enough  
 = 3      input parameter LENWRK not big enough  
 = 5      input parameter L > LDIM  
 = 20     input error returned by lower level routine

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# cfftmi

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## NAME

CFFTMI - initialization routine for CFFTMB and CFFTMF

## SYNOPSIS

```
SUBROUTINE CFFTMI (N, WSAVE, LENSAB, IER)
INTEGER      N, LENSAB, IER
REAL         WSAVE(LENSAB)
```

## DESCRIPTION

FFTPACK 5.0 subroutine CFFTMI initializes array WSAVE for use in its companion routines CFFTMB and CFFTMF. Routine CFFTMI must be called before the first call to CFFTMB or CFFTMF, and after whenever the value of integer N changes.

### Input Arguments

**N** Integer length of each sequence to be transformed. The transform is most efficient when N is a product of small primes.

**LENSAB** Integer dimension of WSAVE array. LENSAB must be at least  $2*N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

### Output Arguments

**WSAVE** Real work array with dimension LENSAB, containing the prime factors of N and also containing certain trigonometric values which will be used in routines CFFTMB or CFFTMF.

IER       = 0 successful exit  
          = 2 input parameter LENS AV not big enough

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# cfftmb

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## NAME

CFFTMB - complex, multiple backward fast Fourier transform

## SYNOPSIS

```
SUBROUTINE CFFTMB (LOT, JUMP, N, INC, C, LENC, WSAVE, LENSAB,  
1                  WORK, LENWRK, IER)
```

```
INTEGER    LOT, JUMP, N, INC, LENC, LENSAB, LENWRK, IER  
COMPLEX    C(LENC)  
REAL       WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine CFFTMB computes the one-dimensional Fourier transform of multiple periodic sequences within a complex array. This transform is referred to as the backward transform or Fourier synthesis, transforming the sequences from spectral to physical space.

This transform is normalized since a call to CFFTMF followed by a call to CFFTMB (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

**LOT** Integer number of sequences to be transformed within array C.

**JUMP** Integer increment between the locations, in array C, of the first elements of two consecutive sequences to be transformed.

N Integer length of each sequence to be transformed. The transform is most efficient when N is a product of small primes.

INC Integer increment between the locations, in array C, of two consecutive elements within the same sequence to be transformed.

C Complex array containing LOT sequences, each having length N, to be transformed. C can have any number of dimensions, but the total number of locations must be at least LENC.

LENC Integer dimension of C array. LENC must be at least  $(LOT-1)*JUMP + INC*(N-1) + 1$ .

WSAVE Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine CFFTMI before the first call to routine CFFTMF or CFFTMB for a given transform length N.

LENSAB Integer dimension of WSAVE array. LENSAB must be at least  $2*N + INT(LOG(REAL(N))) + 4$ .

WORK Real work array of dimension LENWRK.

LENWRK Integer dimension of WORK array. LENWRK must be at least  $2*LOT*N$ .

## Output Arguments

C For index  $L*JUMP+J*INC+1$  where  $J=0, \dots, N-1$  and  $L=0, \dots, LOT-1$ , (that is, for the Jth element of the Lth sequence),

$$C(L*JUMP+J*INC+1) =$$

$$N-1$$

$$\text{SUM } C(L*JUMP+K*INC+1)*\text{EXP}(I*J*K*2*PI/N)$$

K=0

where  $I = \text{SQRT}(-1)$ .

At other indices, the output value of C does not differ from input.

IER       = 0 successful exit  
          = 1 input parameter LENC     not big enough  
          = 2 input parameter LENS AV not big enough  
          = 3 input parameter LENWRK not big enough  
          = 4 input parameters INC,JUMP,N,LOT are not consistent.

The parameters integers INC, JUMP, N and LOT are consistent if equality  
 $I1 \cdot \text{INC} + J1 \cdot \text{JUMP} = I2 \cdot \text{INC} + J2 \cdot \text{JUMP}$  for  $I1, I2 < N$   
and  $J1, J2 < \text{LOT}$  implies  $I1 = I2$  and  $J1 = J2$ .

For multiple FFTs to execute correctly, input variables INC, JUMP, N and LOT must be consistent ... otherwise at least one array element mistakenly is transformed more than once.

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# cfftmf

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## NAME

CFFTMTF - complex, multiple forward fast Fourier transform

## SYNOPSIS

```
SUBROUTINE CFFTMTF (LOT, JUMP, N, INC, C, LENC, WSAVE, LENSAB,  
1                     WORK, LENWRK, IER)
```

```
INTEGER      LOT, JUMP, N, INC, LENC, LENSAB, LENWRK, IER  
COMPLEX      C(LENC)  
REAL         WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine CFFTMTF computes the one-dimensional Fourier transform of multiple periodic sequences within a complex array. This transform is referred to as the forward transform or Fourier analysis, transforming the sequences from physical to spectral space.

This transform is normalized since a call to CFFTMTF followed by a call to CFFTMF (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

LOT Integer number of sequences to be transformed within array C.

JUMP Integer increment between the locations, in array C, of the first elements of two consecutive sequences to be transformed.

N Integer length of each sequence to be transformed. The transform is most efficient when N is a product of small primes.

INC Integer increment between the locations, in array C, of two consecutive elements within the same sequence to be transformed.

C Complex array containing LOT sequences, each having length N, to be transformed. C can have any number of dimensions, but the total number of locations must be at least LENC.

LENC Integer dimension of C array. LENC must be at least  $(LOT-1)*JUMP + INC*(N-1) + 1$ .

WSAVE Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine CFFTMI before the first call to routine CFFTMF or CFFTMB for a given transform length N.

LENSAB Integer dimension of WSAVE array. LENSAB must be at least  $2*N + INT(LOG-REAL(N)) + 4$ .

WORK Real work array of dimension LENWRK.

LENWRK Integer dimension of WORK array. LENWRK must be at least  $2*LOT*N$ .

## Output Arguments

C For index  $L*JUMP + J*INC + 1$  where  $J=0, \dots, N-1$  and  $L=0, \dots, LOT-1$ , (that is, for the Jth element of the Lth sequence),

$$C(L*JUMP+J*INC+1) =$$

$$N-1$$

$$\text{SUM } C(L*JUMP+K*INC+1)*\text{EXP}(-I*J*K*2*PI/N)$$

K=0

where  $I = \text{SQRT}(-1)$ .

At other indices, the output value of C does not differ from input.

IER       = 0 successful exit  
          = 1 input parameter LENC     not big enough  
          = 2 input parameter LENS AV not big enough  
          = 3 input parameter LENWRK not big enough  
          = 4 input parameters INC,JUMP,N,LOT are not consistent.

The parameters integers INC, JUMP, N and LOT are consistent if equality  
 $I1 \cdot \text{INC} + J1 \cdot \text{JUMP} = I2 \cdot \text{INC} + J2 \cdot \text{JUMP}$  for  $I1, I2 < N$   
and  $J1, J2 < \text{LOT}$  implies  $I1 = I2$  and  $J1 = J2$ .

For multiple FFTs to execute correctly, input variables INC, JUMP, N and LOT must be consistent ... otherwise at least one array element mistakenly is transformed more than once.

---

# rfft1i

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---

## NAME

RFFT1I - initialization routine for RFFT1B and RFFT1F

## SYNOPSIS

```
SUBROUTINE RFFT1I (N, WSAVE, LENSAB, IER)
INTEGER          N, LENSAB, IER
REAL             WSAVE(LENSAB)
```

## DESCRIPTION

FFTPACK 5.0 subroutine RFFT1I initializes array WSAVE for use in its companion routines RFFT1B and RFFT1F. The prime factorization of N together with a tabulation of the trigonometric functions are computed and stored in array WSAVE. Separate WSAVE arrays are required for different values of N.

### Input Arguments

N	Integer length of the sequence to be transformed. The transform is most efficient when N is a product of small primes.
LENSAB	Integer dimension of WSAVE array. LENSAB must be at least $N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

### Output Arguments

WSAVE	Real work array with dimension LENSAB, containing the prime factors of N and also containing certain trigonometric values which will be used in routines RFFT1B or RFFT1F.
-------	--

IER        =    0   successful exit  
          =    2   input parameter LENSAB not big enough

---

# rfft1b

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---

## NAME

RFFT1B - real backward fast Fourier transform

## SYNOPSIS

```
SUBROUTINE RFFT1B (N, INC, R, LENR, WSAVE, LENSAB, WORK, LENWRK, IER)
```

```
INTEGER      N, INC, LENR, LENSAB, LENWRK, IER  
REAL        R(LENR), WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine RFFT1B computes the one-dimensional Fourier transform of a periodic sequence within a real array. This is referred to as the backward transform or Fourier synthesis, transforming the sequence from spectral to physical space.

This transform is normalized since a call to RFFT1B followed by a call to RFFT1F (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

- |     |  |
|-----|--|
| N   | Integer length of the sequence to be transformed. The transform is most efficient when N is a product of small primes. |
| INC | Integer increment between the locations, in array R, of two consecutive elements within the sequence.                  |
| R   | Real array of length LENR containing the sequence to be transformed.   |

LENR Integer dimension of R array. LENR must be at least  $INC*(N-1) + 1$ .

WSAVE Real work array o length LENSAB. WSAVE's contents must be initialized with a call to subroutine RFFT1I before the first call to routine RFFT1F or RFFT1B for a given transform length N.

LENSAB Integer dimension of WSAVE array. LENSAB must be at least  $N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

WORK Real work array of dimension LENWRK.

LENWRK Integer dimension of WORK array. LENWRK must be at N.

## Output Arguments

R Real output array R. For purposes of exposition, assume R's range of indices is given by  $R(0:(N-1)*INC)$ .

The output values of R are written over the input values. If N is even, set  $NH=N/2-1$ ; then for  $J=0, \dots, N-1$

$$\begin{aligned} R(J*INC) = & R(0) + \\ & [ (-1)**J*R((N-1)*INC) ] \\ & + \sum_{N1=1}^{NH} R((2*N1-1)*INC)*\text{COS}(J*N1*2*PI/N) \\ & + \sum_{N1=1}^{NH} R(2*N1*INC)*\text{SIN}(J*N1*2*PI/N) \end{aligned}$$

If N is odd, set  $NH=(N-1)/2$  and define R as above, except remove the expression in square brackets [].

IER      Integer error return  
= 0 successful exit  
= 1 input parameter LENR    not big enough  
= 2 input parameter LENSAB not big enough  
= 3 input parameter LENWRK not big enough

---



# rfft1f

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---

## NAME

RFFT1F - real backward fast Fourier transform

## SYNOPSIS

```
SUBROUTINE RFFT1F (N, INC, R, LENR, WSAVE, LENSAB, WORK, LENWRK, IER)
```

```
INTEGER      N, INC, LENR, LENSAB, LENWRK, IER  
REAL        R(LENR), WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine RFFT1F computes the one-dimensional Fourier transform of a periodic sequence within a real array. This is referred to as the forward transform or Fourier analysis, transforming the sequence from physical to spectral space.

This transform is normalized since a call to RFFT1F followed by a call to RFFT1B (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

- |     |  |
|-----|--|
| N   | Integer length of the sequence to be transformed. The transform is most efficient when N is a product of small primes. |
| INC | Integer increment between the locations, in array R, of two consecutive elements within the sequence.                  |
| R   | Real array of length LENR containing the sequence to be transformed.   |

LENR Integer dimension of R array. LENR must be at least  $INC*(N-1) + 1$ .

WSAVE Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine RFFT1I before the first call to routine RFFT1F or RFFT1B for a given transform length N.

LENSAB Integer dimension of WSAVE array. LENSAB must be at least  $N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

WORK Real work array of dimension LENWRK.

LENWRK Integer dimension of WORK array. LENWRK must be at N.

#### Output Arguments

R Real output array R. For purposes of exposition, assume R's range of indices is given by  $R(0:(N-1)*INC)$ .

Then

$$R(0) = \sum_{N1=0}^{N-1} R(N1*INC)/N$$

If N is even, set  $NH=N/2-1$ ; if N is odd set  $NH=(N-1)/2$ ; then for  $J=1, \dots, NH$

$$R((2*J-1)*INC) =$$

$$2.*\sum_{N1=0}^{N-1} (R(N1*INC)*\text{COS}(J*N1*2*PI/N))/N$$

and

$R(2*J*INC) =$

$$2.*\sum_{N1=0}^{N-1} (R(N1*INC)*\sin(J*N1*2*PI/N))/N$$

Also if N is even then

$R((N-1)*INC) =$

$$\sum_{N1=0}^{N-1} (-1)**N1*R(N1*INC)/N$$

IER      Integer error return  
= 0 successful exit  
= 1 input parameter LENR      not big enough  
= 2 input parameter LENSAB not big enough  
= 3 input parameter LENWRK not big enough

---

# rfft2i

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---

## NAME

RFFT2I - initialization routine for RFFT2B and RFFT2F

## SYNOPSIS

```
SUBROUTINE RFFT2I (L, M, WSAVE, LENSAB, IER)
INTEGER      L, M, LENSAB, IER
REAL         WSAVE(LENSAB)
```

## DESCRIPTION

FFTPACK 5.0 routine RFFT2I initializes real array WSAVE for use in its companion routines RFFT2F and RFFT2B for computing the two-dimensional fast Fourier transform of real data. Prime factorizations of L and M, together with tabulations of the trigonometric functions, are computed and stored in array WSAVE. RFFT2I must be called prior to the first call to RFFT2F or RFFT2B. Separate WSAVE arrays are required for different values of L or M.

### Input Arguments

- |        |  |
|--------|--|
| L      | Integer number of elements to be transformed in the first dimension. The transform is most efficient when L is a product of small primes.                              |
| M      | Integer number of elements to be transformed in the second dimension. The transform is most efficient when M is a product of small primes.                             |
| LENSAB | Integer number of elements in the WSAVE array. LENSAB must be at least $L + M + \text{INT}(\text{LOG}(\text{REAL}(L))) + \text{INT}(\text{LOG}(\text{REAL}(M))) + 8$ . |

## Output Arguments

WSAVE     Real work array with dimension LENSAB, containing the prime factors of L and M, and also containing certain trigonometric values which will be used in routines RFFT2B or RFFT2F.

IER       Integer error return  
= 0 successful exit  
= 2 input parameter LENSAB not big enough  
= 20 input error returned by lower level routine

---

# rfft2b

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---

## NAME

RFFT2B - complex to real, two-dimensional backward fast Fourier transform

## SYNOPSIS

```
SUBROUTINE RFFT2B (LDIM, L, M, R, WSAVE, LENSAB, WORK, LENWRK, IER)
INTEGER          LDIM, L, M, LENSAB, LENWRK, IER
REAL             R(LDIM,M), WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine RFFT2B computes the two-dimensional discrete Fourier transform of the complex Fourier coefficients a real periodic array. This transform is known as the backward transform or Fourier synthesis, transforming from spectral to physical space.

Routine RFFT2B is normalized: a call to RFFT2B followed by a call to RFFT2F (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

LDIM	Integer first dimension of the two-dimensional real array R, which must be at least $2*(L/2+1)$ .
L	Integer number of elements to be transformed in the first dimension of the two-dimensional real array R. The value of L must be less than or equal to that of LDIM. The transform is most efficient when L is a product of small primes.
M	Integer number of elements to be transformed in the second

dimension of the two-dimensional real array R. The transform is most efficient when M is a product of small primes.

- R Real array of two dimensions containing the  $L/2+1$ -by-M complex subarray of spectral coefficients. R's first dimension is LDIM and its second dimension must be at least as large as M.
- WSAVE Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine RFFT2I before the first call to routine RFFT2F or RFFT2B with lengths L and M. WSAVE's contents may be re-used for subsequent calls to RFFT2F and RFFT2B with the same transform lengths L and M.
- LENSAB Integer number of elements in the WSAVE array. LENSAB must be at least  $L + M + \text{INT}(\text{LOG}(\text{REAL}(L))) + \text{INT}(\text{LOG}(\text{REAL}(M))) + 8$ .
- WORK Real array of dimension LENWRK, where LENWRK is defined below. WORK provides workspace, and its contents need not be saved between calls to routines RFFT2B and RFFT2F.
- LENWRK Integer number of elements in the WORK array. LENWRK must be at least LDIM\*M.

## Output Arguments

- R Real output array R of size LDIM-by-M, where LDIM is at least L. For purposes of exposition, assume the index ranges of array R are defined by  $R(0:L-1,0:M-1)$ , and the complex Fourier coefficient array by  $C(0:L/2,0:M-2)$ .

$$R(I,J) = \sum_{L1=0}^{L/2} \sum_{M1=0}^{M-1} C(L1,M1)$$

$$* \text{EXP}(\text{SQRT}(-1) * 2 * \text{PI} * (I * L1 / L + J * M1 / M))$$

$$L-1 \quad M-1$$

```
      + SUM  SUM  CONJ(C(L1,M1))  
L1=L/2+1  M1=0
```

```
      *EXP(SQRT(-1)*2*PI*(I*(L-L1)/L+J*M1/M))
```

```
IER      Integer error return  
= 0      successful exit  
= 2      input parameter LENSAB not big enough  
= 3      input parameter LENWRK not big enough  
= 6      input parameter LDIM < 2*(L/2+1)  
= 20     input error returned by lower level routine
```

---



# rfft2f

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---

## NAME

RFFT2F - real to complex, two-dimensional forward fast Fourier transform

## SYNOPSIS

```
SUBROUTINE RFFT2F (LDIM, L, M, R, WSAVE, LENSAB, WORK, LENWRK, IER)
INTEGER    LDIM, L, M,  LENSAB, LENWRK, IER
REAL      R(LDIM,M), WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine RFFT2F computes the two-dimensional discrete Fourier transform of a real periodic array. This transform is known as the forward transform or Fourier analysis, transforming from physical to spectral space.

Routine RFFT2F is normalized: a call to RFFT2F followed by a call to RFFT2B (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

- |      |  |
|------|--|
| LDIM | Integer first dimension of the two-dimensional real array R, which must be at least $2*(L/2+1)$ .  |
| L    | Integer number of elements to be transformed in the first dimension of the two-dimensional real array R. The value of L must be less than or equal to that of LDIM. The transform is most efficient when L is a product of small primes. |
| M    | Integer number of elements to be transformed in the second   |

dimension of the two-dimensional real array R. The transform is most efficient when M is a product of small primes.

R Real array of two dimensions containing the L-by-M subarray to be transformed. R's first dimension is LDIM and its second dimension must be at least as large as M.

WSAVE Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine RFFT2I before the first call to routine RFFT2F or RFFT2B with lengths L and M. WSAVE's contents may be re-used for subsequent calls to RFFT2F and RFFT2B with the same transform lengths.

LENSAB Integer number of elements in the WSAVE array. LENSAB must be at least  $L + M + \text{INT}(\text{LOG}(\text{REAL}(L))) + \text{INT}(\text{LOG}(\text{REAL}(M))) + 8$ .

WORK Real array of dimension LENWRK which is defined below. WORK provides workspace, and its contents need not be saved between calls to routines RFFT2F and RFFT2B.

LENWRK Integer number of elements in the WORK array. LENWRK must be at least LDIM\*M.

## Output Arguments

R Real output array of two dimensions. Only half of the Fourier spectrum of R is computed and stored as a  $L/2+1$ -by- M complex array. The L wavenumbers stored are 0 through  $L/2+1$ . The leading dimension of R LDIM must be at least  $2*(L/2+1)$ .

For purposes of exposition, assume the index ranges of a complex array C are defined by  $C(0:L/2, 0:M-1)$ .

For  $I=0, \dots, L/2$  and  $J=0, \dots, M-1$ , the  $C(I,J)$ 's are given in the traditional aliased form by

$$L-1 \quad M-1$$

$$C(I,J) = \frac{1}{(L*M)} \sum_{L1=0} \sum_{M1=0} C(L1,M1) * \\$$

$$\text{EXP}(-\text{SQRT}(-1)*2*\text{PI}*(I*L1/L + J*M1/M))$$

The complex  $C(I,J)$ ,  $I=0,\dots,L/2$  and  $J=0,\dots,M-1$  are stored in the real array  $R$  as:

$$\begin{aligned} \text{Re}(C(I,J)) &= R(2*I+1,J+1) \\ \text{Im}(C(I,J)) &= R(2*I+2,J+1). \end{aligned}$$

IER      Integer error return  
 = 0 successful exit  
 = 2 input parameter LENSAB not big enough  
 = 3 input parameter LENWRK not big enough  
 = 6 input parameter LDIM < 2\*(L+1)  
 = 20 input error returned by lower level routine

---

# rfftmi

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---

## NAME

RFFTMI - initialization routine for RFFTMB and RFFTMF

## SYNOPSIS

```
SUBROUTINE RFFTMI (N, WSAVE, LENSAB, IER)
INTEGER          N, LENSAB, IER
REAL             WSAVE(LENSAB)
```

## DESCRIPTION

FFTPACK 5.0 subroutine RFFTMI initializes array WSAVE for use in its companion routines RFFTMB and RFFTMF. The prime factorization of N together with a tabulation of the trigonometric functions are computed and stored in array WSAVE. Separate WSAVE arrays are required for different values of N.

### Input Arguments

N	Integer length of each sequence to be transformed. The transform is most efficient when N is a product of small primes.
LENSAB	Integer dimension of WSAVE array. LENSAB must be at least $N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

### Output Arguments

WSAVE	Real work array with dimension LENSAB, containing the prime factors of N and also containing certain trigonometric values which will be used in routines RFFTMB or RFFTMF.
-------	--

IER        =    0   successful exit  
          =    2   input parameter LENS AV not big enough

---

# rfftmb

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---

## NAME

RFFTMB - real, multiple backward fast Fourier transform

## SYNOPSIS

```
SUBROUTINE RFFTMB (LOT, JUMP, N, INC, R, LENR, WSAVE, LENSAB,  
1                  WORK, LENWRK, IER)
```

```
INTEGER    LOT, JUMP, N, INC, LENR, LENSAB, LENWRK, IER  
REAL       R(LENR), WSAVE(LENSAB)      ,WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine RFFTMB computes the one-dimensional Fourier transform of multiple periodic sequences within a real array. This transform is referred to as the backward transform or Fourier synthesis, transforming the sequences from spectral to physical space.

This transform is normalized since a call to RFFTMB followed by a call to RFFTMF (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

LOT Integer number of sequences to be transformed within array R.

JUMP Integer increment between the locations, in array R, of the first elements of two consecutive sequences to be transformed.

N Integer length of each sequence to be transformed. The

transform is most efficient when N is a product of small primes.

- INC      Integer increment between the locations, in array R, of two consecutive elements within the same sequence.
- R        Real array containing LOT sequences, each having length N. R can have any number of dimensions, but the total number of locations must be at least LENR.
- LENR    Integer dimension of R array. LENR must be at least  $(\text{LOT}-1)*\text{JUMP} + \text{INC}*(\text{N}-1) + 1$ .
- WSAVE   Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine RFFFTMI before the first call to routine RFFFTMF or RFFFTMB for a given transform length N.
- LENSAB   Integer dimension of WSAVE array. LENSAB must be at least  $\text{N} + \text{INT}(\text{LOG}(\text{REAL}(\text{N}))) + 4$ .
- WORK    Real work array of dimension LENWRK.
- LENWRK   Integer dimension of WORK array. LENWRK must be at least  $\text{LOT}*\text{N}$ .

#### Output Arguments

- R        Real output array R. For purposes of exposition, assume R's range of indices is given by  $\text{R}(0:(\text{LOT}-1)*\text{JUMP}+(\text{N}-1)*\text{INC})$ .

The output values of R are written over the input values. If N is even, set  $\text{NH}=\text{N}/2-1$ ; then for  $\text{I}=0,\dots,\text{LOT}-1$  and  $\text{J}=0,\dots,\text{N}-1$

$$\begin{aligned} \text{R}(\text{I}*\text{JUMP}+\text{J}*\text{INC}) = & \quad \text{R}(\text{I}*\text{JUMP}) + \\ & [ (-1)**\text{J}*\text{R}(\text{I}*\text{JUMP}+(\text{N}-1)*\text{INC}) ] \end{aligned}$$

$$\begin{aligned}
& + \sum_{N1=1}^{NH} R(I * JUMP + (2 * N1 - 1) * INC) * \cos(J * N1 * 2 * \pi / N) \\
& + \sum_{N1=1}^{NH} R(I * JUMP + 2 * N1 * INC) * \sin(J * N1 * 2 * \pi / N)
\end{aligned}$$

If N is odd, set  $NH = (N-1)/2$  and define R as above, except remove the expression in square brackets [].

IER Integer error return  
 = 0 successful exit  
 = 1 input parameter LENR not big enough  
 = 2 input parameter LENS AV not big enough  
 = 3 input parameter LENWRK not big enough  
 = 4 input parameters INC, JUMP, N, LOT are not consistent.

The parameters integers INC, JUMP, N and LOT are consistent if equality  
 $I1 * INC + J1 * JUMP = I2 * INC + J2 * JUMP$  for  $I1, I2 < N$   
 and  $J1, J2 < LOT$  implies  $I1 = I2$  and  $J1 = J2$ .

For multiple FFTs to execute correctly, input variables INC, JUMP, N and LOT must be consistent ... otherwise at least one array element mistakenly is transformed more than once.

---



# rfftmf

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---

## NAME

RFFTMF - real, multiple forward fast Fourier transform

## SYNOPSIS

```
SUBROUTINE RFFTMF (LOT, JUMP, N, INC, R, LENR, WSAVE, LENSAB,  
1                  WORK, LENWRK, IER)
```

```
INTEGER    LOT, JUMP, N, INC, LENR, LENSAB, LENWRK, IER  
REAL       R(LENR), WSAVE(LENSAB)      ,WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine RFFTMF computes the one-dimensional Fourier transform of multiple periodic sequences within a real array. This transform is referred to as the forward transform or Fourier analysis, transforming the sequences from physical to spectral space.

This transform is normalized since a call to RFFTMF followed by a call to RFFTMB (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

LOT Integer number of sequences to be transformed within array R.

JUMP Integer increment between the locations, in array R, of the first elements of two consecutive sequences to be transformed.

N Integer length of each sequence to be transformed. The

transform is most efficient when N is a product of small primes.

- INC Integer increment between the locations, in array R, of two consecutive elements within the same sequence.
- R Real array containing LOT sequences, each having length N. R can have any number of dimensions, but the total number of locations must be at least LENR.
- LENR Integer dimension of R array. LENR must be at least  $(\text{LOT}-1)*\text{JUMP} + \text{INC}*(\text{N}-1) + 1$ .
- WSAVE Real work array of length LENS AV. WSAVE's contents must be initialized with a call to subroutine RFF TMI before the first call to routine RFF TMF or RFF TMB for a given transform length N.
- LENS AV Integer dimension of WSAVE array. LENS AV must be at least  $\text{N} + \text{INT}(\text{LOG}(\text{REAL}(\text{N}))) + 4$ .
- WORK Real work array of dimension LENWRK.
- LENWRK Integer dimension of WORK array. LENWRK must be at least  $\text{LOT}*\text{N}$ .

## Output Arguments

- R Real output array R. For purposes of exposition, assume R's range of indices is given by  $\text{R}(0:(\text{LOT}-1)*\text{JUMP}+(\text{N}-1)*\text{INC})$ .

Then for  $\text{I}=0, \dots, \text{LOT}-1$

$$\text{R}(\text{I}*\text{JUMP}) = \sum_{\text{N1}=0}^{\text{N}-1} \text{R}(\text{I}*\text{JUMP}+\text{N1}*\text{INC})/\text{N}$$

If N is even, set  $\text{NH}=\text{N}/2-1$ ; if N is odd set  $\text{NH}=(\text{N}-1)/2$ ; then for  $\text{J}=1, \dots, \text{NH}$

$$R(I * JUMP + (2 * J - 1) * INC) =$$

$$2. * \sum_{N1=0}^{N-1} (R(I * JUMP + N1 * INC) * \cos(J * N1 * 2 * \pi / N)) / N$$

and

$$R(I * JUMP + 2 * J * INC) =$$

$$2. * \sum_{N1=0}^{N-1} (R(I * JUMP + N1 * INC) * \sin(J * N1 * 2 * \pi / N)) / N$$

Also if N is even then

$$R(I * JUMP + (N - 1) * INC) =$$

$$\sum_{N1=0}^{N-1} (-1)^{N1} * R(I * JUMP + N1 * INC) / N$$

IER Integer error return  
 = 0 successful exit  
 = 1 input parameter LENR not big enough  
 = 2 input parameter LENS AV not big enough  
 = 3 input parameter LENWRK not big enough  
 = 4 input parameters INC,JUMP,N,LOT are not consistent.

The parameters integers INC, JUMP, N and LOT are consistent if equality  
 $I1 * INC + J1 * JUMP = I2 * INC + J2 * JUMP$  for  $I1, I2 < N$   
 and  $J1, J2 < LOT$  implies  $I1 = I2$  and  $J1 = J2$ .

For multiple FFTs to execute correctly, input variables INC, JUMP, N and LOT must be consistent ... otherwise at least one array element mistakenly is transformed more than once.

---

# cost1i

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## NAME

COST1I - initialization routine for COST1B and COST1F

## SYNOPSIS

```
SUBROUTINE COST1I (N, WSAVE, LENSAB, IER)
INTEGER          N, LENSAB, IER
REAL             WSAVE(LENSAB)
```

## DESCRIPTION

FFTPACK 5.0 subroutine COST1I initializes array WSAVE for use in its companion routines COST1F and COST1B. The prime factorization of N together with a tabulation of the trigonometric functions are computed and stored in array WSAVE. Separate WSAVE arrays are required for different values of N.

### Input Arguments

N	Integer length of the sequence to be transformed. The transform is most efficient when N-1 is a product of small primes.
LENSAB	Integer dimension of WSAVE array. LENSAB must be at least $2*N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

### Output Arguments

WSAVE	Real work array with dimension LENSAB, containing the prime factors of N and also containing certain trigonometric values which will be used in routines COST1B or COST1F.
-------	--

IER      Integer error return  
= 0 successful exit  
= 2 input parameter LENS AV not big enough  
= 20 input error returned by lower level routine

---

# cost1b

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---

## NAME

COST1B - real backward cosine fast Fourier transform

## SYNOPSIS

```
SUBROUTINE COST1B (N, INC, R, LENR, WSAVE, LENSAB, WORK, LENWRK, IER)
```

```
INTEGER      N, INC, LENR, LENSAB, LENWRK, IER  
REAL        R(LENR), WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine COST1B computes the one-dimensional Fourier transform of an even sequence within a real array. This transform is referred to as the backward transform or Fourier synthesis, transforming the sequence from spectral to physical space.

This transform is normalized since a call to COST1B followed by a call to COST1F (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

N            Integer length of the sequence to be transformed. The transform is most efficient when N-1 is a product of small primes.

INC          Integer increment between the locations, in array R, of two consecutive elements within the sequence.

R            Real array of length LENR containing the sequence to be transformed.

LENR Integer dimension of R array. LENR must be at least  $INC*(N-1)+1$ .

WSAVE Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine COST1I before the first call to routine COST1F or COST1B for a given transform length N. WSAVE's contents may be re-used for subsequent calls to COST1F and COST1B with the same N.

LENSAB Integer dimension of WSAVE array. LENSAB must be at least  $2*N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

WORK Real work array of dimension at least LENWRK.

LENWRK Integer dimension of WORK array. LENWRK must be at least N-1.

#### Output Arguments

R Real output array R. For purposes of exposition, assume R's range of indices is given by  $R(0:(N-1)*INC)$ .

The output values of R are written over the input values.  
For  $J=0, \dots, N-1$

$$R(J*INC) =$$

$$\sum_{N1=0}^{N-1} R(N1*INC) * \cos(J*N1*PI/(N-1))$$

IER Integer error return

- = 0 successful exit
- = 1 input parameter LENR not big enough
- = 2 input parameter LENSAB not big enough
- = 3 input parameter LENWRK not big enough
- = 20 input error returned by lower level routine

---



# cost1f

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---

## NAME

COST1F - real backward cosine fast Fourier transform

## SYNOPSIS

```
SUBROUTINE COST1F (N, INC, R, LENR, WSAVE, LENSAB, WORK, LENWRK, IER)
```

```
INTEGER      N, INC, LENR, LENSAB, LENWRK, IER  
REAL        R(LENR), WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine COST1F computes the one-dimensional Fourier transform of an even sequence within a real array. This transform is referred to as the forward transform or Fourier analysis, transforming the sequence from physical to spectral space.

This transform is normalized since a call to COST1F followed by a call to COST1B (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

N            Integer length of the sequence to be transformed. The transform is most efficient when N-1 is a product of small primes.

INC          Integer increment between the locations, in array R, of two consecutive elements within the sequence.

R            Real array of length LENR containing the sequence to be transformed.

LENR Integer dimension of R array. LENR must be at least  $INC*(N-1)+1$ .

WSAVE Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine COST1I before the first call to routine COST1F or COST1B for a given transform length N. WSAVE's contents may be re-used for subsequent calls to COST1F and COST1B with the same N.

LENSAB Integer dimension of WSAVE array. LENSAB must be at least  $2*N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

WORK Real work array of dimension at least LENWRK.

LENWRK Integer dimension of WORK array. LENWRK must be at least N-1.

#### Output Arguments

R Real output array R. For purposes of exposition, assume R's range of indices is given by  $R(0:(N-1)*INC)$ .

The output values of R are written over the input values.

$R(0) =$

$0.5*X(0)/(N-1)$

$N-2$   
 $+ \text{SUM}_{N1=1} R(N1*INC)/(N-1)$

$+ 0.5*X((N-1)*INC)/(N-1)$

For  $J=1, \dots, N-2$

$R(J*INC) =$

$R(0)/(N-1)$

$$+ \sum_{N1=1}^{N-2} 2.0 * (X(N1*INC) * \cos(J*N1*PI/(N-1))) / (N-1)$$

$$+ ((-1)**J) * X((N-1)*INC) / (N-1)$$

$R((N-1)*INC) =$

$0.5 * X(0) / (N-1)$

$$+ \sum_{N1=1}^{N-2} R(N1*INC) * ((-1)**N1) / (N-1)$$

$$+ 0.5 * ((-1)**(N-1)) * X((N-1)*INC) / (N-1)$$

IER      Integer error return  
= 0    successful exit  
= 1    input parameter LENR    not big enough  
= 2    input parameter LENSAB not big enough  
= 3    input parameter LENWRK not big enough  
= 20   input error returned by lower level routine

---

# costmi

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---

## NAME

COSTMI - initialization routine for COSTMB and COSTMF

## SYNOPSIS

```
SUBROUTINE COSTMI (N, WSAVE, LENSAB, IER)
INTEGER      N, LENSAB, IER
REAL         WSAVE(LENSAB)
```

## DESCRIPTION

FFTPACK 5.0 subroutine COSTMI initializes array WSAVE for use in its companion routines COSTMF and COSTMB. The prime factorization of N together with a tabulation of the trigonometric functions are computed and stored in array WSAVE. Separate WSAVE arrays are required for different values of N.

### Input Arguments

N	Integer length of each sequence to be transformed. The transform is most efficient when N is a product of small primes.
LENSAB	Integer dimension of WSAVE array. LENSAB must be at least $2*N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$

### Output Arguments

WSAVE	Real work array with dimension LENSAB, containing the prime factors of N and also containing certain trigonometric values which will be used in routines COSTMB or COSTMF.
-------	--

IER      Integer error return  
= 0 successful exit  
= 2 input parameter LENS AV not big enough  
= 20 input error returned by lower level routine

---

# costmb

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---

## NAME

COSTMB - real, multiple backward cosine fast Fourier transform

## SYNOPSIS

```
SUBROUTINE COSTMB (LOT, JUMP, N, INC, R, LENR, WSAVE, LENSAB,  
1                  WORK, LENWRK, IER)
```

```
INTEGER    LOT, JUMP, N, INC, LENR, LENSAB, LENWRK, IER  
REAL       R(LENR), WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine COSTMB computes the one-dimensional Fourier transform of multiple even sequences within a real array. This transform is referred to as the backward transform or Fourier synthesis, transforming the sequences from spectral to physical space.

This transform is normalized since a call to COSTMB followed by a call to COSTMF (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

LOT Integer number of sequences to be transformed within array R.

JUMP Integer increment between the locations, in array R, of the first elements of two consecutive sequences to be transformed.

N Integer length of each sequence to be transformed. The

transform is most efficient when  $N-1$  is a product of small primes.

- INC      Integer increment between the locations, in array R, of two consecutive elements within the same sequence.
- R        Real array containing LOT sequences, each having length N. R can have any number of dimensions, but the total number of locations must be at least LENR.
- LENR    Integer dimension of R array. LENR must be at least  $(LOT-1)*JUMP + INC*(N-1) + 1$ .
- WSAVE   Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine COSTMI before the first call to routine COSTMF or COSTMB for a given transform length N. WSAVE's contents may be re-used for subsequent calls to COSTMF and COSTMB with the same N.
- LENSAB   Integer dimension of WSAVE array. LENSAB must be at least  $2*N + INT(LOG (REAL(N))) + 4$ .
- WORK    Real work array of dimension at least LENWRK.
- LENWRK   Integer dimension of WORK array. LENWRK must be at least  $LOT*(N+1)$ .

#### Output Arguments

- R        Real output array R. For purposes of exposition, assume R's range of indices is given by  $R(0:(LOT-1)*JUMP+(N-1)*INC)$ .

The output values of R are written over the input values.  
For  $I=0, \dots, LOT-1$  and  $J=0, \dots, N-1$

$$R(I*JUMP+J*INC) =$$

$$N-1$$

```
SUM  R(I*JUMP+N1*INC)*COS(J*N1*PI/(N-1))
N1=0
```

IER Integer error return

- = 0 successful exit
- = 1 input parameter LENR not big enough
- = 2 input parameter LENSAB not big enough
- = 3 input parameter LENWRK not big enough
- = 4 input parameters INC,JUMP,N,LOT are not consistent.
- = 20 input error returned by lower level routine

The parameters integers INC, JUMP, N and LOT are consistent if equality

$I_1*INC + J_1*JUMP = I_2*INC + J_2*JUMP$  for  $I_1, I_2 < N$   
and  $J_1, J_2 < LOT$  implies  $I_1=I_2$  and  $J_1=J_2$ .

For multiple FFTs to execute correctly, input variables INC, JUMP, N and LOT must be consistent, otherwise at least one array element mistakenly is transformed more than once.

---



# costmf

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---

## NAME

COSTMF - real, multiple forward cosine fast Fourier transform

## SYNOPSIS

```
SUBROUTINE COSTMF (LOT, JUMP, N, INC, R, LENR, WSAVE, LENSAB,  
1                  WORK, LENWRK, IER)
```

```
INTEGER    LOT, JUMP, N, INC, LENR, LENSAB, LENWRK, IER  
REAL       R(LENR), WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine COSTMF computes the one-dimensional Fourier transform of multiple even sequences within a real array. This transform is referred to as the forward transform or Fourier analysis, transforming the sequences from physical to spectral space.

This transform is normalized since a call to COSTMF followed by a call to COSTMB (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

LOT Integer number of sequences to be transformed within array R.

JUMP Integer increment between the locations, in array R, of the first elements of two consecutive sequences to be transformed.

N Integer length of each sequence to be transformed. The

transform is most efficient when  $N-1$  is a product of small primes.

- INC Integer increment between the locations, in array R, of two consecutive elements within the same sequence.
- R Real array containing LOT sequences, each having length N. R can have any number of dimensions, but the total number of locations must be at least LENR.
- LENR Integer dimension of R array. LENR must be at least  $(LOT-1)*JUMP + INC*(N-1) + 1$ .
- WSAVE Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine COSTMI before the first call to routine COSTMF or COSTMB for a given transform length N. WSAVE's contents may be re-used for subsequent calls to COSTMF and COSTMB with the same N.
- LENSAB Integer dimension of WSAVE array. LENSAB must be at least  $2*N + INT(LOG (REAL(N))) + 4$ .
- WORK Real work array of dimension at least LENWRK.
- LENWRK Integer dimension of WORK array. LENWRK must be at least  $LOT*(N+1)$ .

#### Output Arguments

- R Real output array R. For purposes of exposition, assume R's range of indices is given by  $R(0:(LOT-1)*JUMP+(N-1)*INC)$ .

The output values of R are written over the input values.

For  $I=0, \dots, LOT-1$

$R(I*JUMP) =$

$$0.5 * X(I*JUMP) / (N-1)$$

$$\begin{aligned}
& N-2 \\
& + \text{SUM}_{N1=1} R(I * \text{JUMP} + N1 * \text{INC}) / (N-1) \\
& + 0.5 * X(I * \text{JUMP} + (N-1) * \text{INC}) / (N-1)
\end{aligned}$$

For  $I=0, \dots, \text{LOT}-1$  and  $J=1, \dots, N-2$   
 $R(I * \text{JUMP} + J * \text{INC}) =$

$$\begin{aligned}
& R(I * \text{JUMP}) / (N-1) \\
& + \text{SUM}_{N1=1}^{N-2} 2.0 * (X(I * \text{JUMP} + N1 * \text{INC}) * \cos(J * N1 * \pi / (N-1))) / (N-1) \\
& + ((-1)^J) * X(I * \text{JUMP} + (N-1) * \text{INC}) / (N-1)
\end{aligned}$$

For  $I=0, \dots, \text{LOT}-1$   
 $R(I * \text{JUMP} + (N-1) * \text{INC}) =$

$$\begin{aligned}
& 0.5 * X(I * \text{JUMP}) / (N-1) \\
& + \text{SUM}_{N1=1}^{N-2} R(I * \text{JUMP} + N1 * \text{INC}) * ((-1)^{N1}) / (N-1) \\
& + 0.5 * ((-1)^{(N-1)}) * X(I * \text{JUMP} + (N-1) * \text{INC}) / (N-1)
\end{aligned}$$

IER Integer error return  
= 0 successful exit  
= 1 input parameter LENR not big enough  
= 2 input parameter LENS AV not big enough  
= 3 input parameter LENWRK not big enough  
= 4 input parameters INC, JUMP, N, LOT are not consistent.  
= 20 input error returned by lower level routine

The parameters integers INC, JUMP, N and LOT are consistent if equality  
 $I1 * \text{INC} + J1 * \text{JUMP} = I2 * \text{INC} + J2 * \text{JUMP}$  for  $I1, I2 < N$   
and  $J1, J2 < \text{LOT}$  implies  $I1=I2$  and  $J1=J2$ .

For multiple FFTs to execute correctly, input variables

INC, JUMP, N and LOT must be consistent, otherwise at least one array element mistakenly is transformed more than once.

---

# sint1i

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---

## NAME

SINT1I - initialization routine for SINT1B and SINT1F

## SYNOPSIS

```
SUBROUTINE SINT1I (N, WSAVE, LENSAB, IER)
INTEGER      N, LENSAB, IER
REAL         WSAVE(LENSAB)
```

## DESCRIPTION

FFTPACK 5.0 subroutine SINT1I initializes array WSAVE for use in its companion routines SINT1F and SINT1B. The prime factorization of N together with a tabulation of the trigonometric functions are computed and stored in array WSAVE. Separate WSAVE arrays are required for different values of N.

### Input Arguments

N	Integer length of the sequence to be transformed. The transform is most efficient when N+1 is a product of small primes.
LENSAB	Integer dimension of WSAVE array. LENSAB must be at least $N/2 + N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

### Output Arguments

WSAVE	Real work array with dimension LENSAB, containing the prime factors of N and also containing certain trigonometric values which will be used in routines SINT1B or SINT1F.
-------	--

IER      Integer error return  
= 0 successful exit  
= 2 input parameter LENS AV not big enough  
= 20 input error returned by lower level routine

---

# sint1b

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---

## NAME

SINT1B - real backward sine fast Fourier transform

## SYNOPSIS

```
SUBROUTINE SINT1B (N, INC, R, LENR, WSAVE, LENSAB, WORK, LENWRK, IER)
```

```
INTEGER      N, INC, LENR, LENSAB, LENWRK, IER
```

```
REAL         R(LENR), WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine SINT1B computes the one-dimensional Fourier transform of an odd sequence within a real array. This transform is referred to as the backward transform or Fourier synthesis, transforming the sequence from spectral to physical space.

This transform is normalized since a call to SINT1B followed by a call to SINT1F (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

N            Integer length of the sequence to be transformed. The transform is most efficient when N+1 is a product of small primes.

INC          Integer increment between the locations, in array R, of two consecutive elements within the sequence.

R            Real array of length LENR containing the sequence to be transformed.

LENR Integer dimension of R array. LENR must be at least  $INC*(N-1)+1$ .

WSAVE Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine SINT1I before the first call to routine SINT1F or SINT1B for a given transform length N. WSAVE's contents may be re-used for subsequent calls to SINT1F and SINT1B with the same N.

LENSAB Integer dimension of WSAVE array. LENSAB must be at least  $N/2 + N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

WORK Real work array of dimension at least LENWRK.

LENWRK Integer dimension of WORK array. Must be at least  $2*N+2$ .

#### Output Arguments

R Real output array. For purposes of exposition, assume R's range of indices is given by  $R(INC:N*INC)$ .

The output values of R are written over the input values.  
For  $J=1, \dots, N$

$R(J*INC) =$

$$\sum_{N1=1}^N R(N1*INC) * \text{SIN}(J*N1*PI/(N+1))$$

IER Integer error return  
= 0 successful exit  
= 1 input parameter LENR not big enough  
= 2 input parameter LENSAB not big enough  
= 3 input parameter LENWRK not big enough  
= 20 input error returned by lower level routine





# sint1f

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---

## NAME

SINT1F - real forward sine fast Fourier transform

## SYNOPSIS

```
SUBROUTINE SINT1F (N, INC, R, LENR, WSAVE, LENSAB, WORK, LENWRK, IER)
```

```
INTEGER      N, INC, LENR, LENSAB, LENWRK, IER
```

```
REAL         R(LENR), WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine SINT1F computes the one-dimensional Fourier transform of an odd sequence within a real array. This transform is referred to as the forward transform or Fourier analysis, transforming the sequence from physical to spectral space.

This transform is normalized since a call to SINT1F followed by a call to SINT1B (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

N       Integer length of the sequence to be transformed. The transform is most efficient when N+1 is a product of small primes.

INC     Integer increment between the locations, in array R, of two consecutive elements within the sequence.

R       Real array of length LENR containing the sequence to be transformed.

LENR Integer dimension of R array. LENR must be at least  $INC*(N-1)+1$ .

WSAVE Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine SINT1I before the first call to routine SINT1F or SINT1B for a given transform length N. WSAVE's contents may be re-used for subsequent calls to SINT1F and SINT1B with the same N.

LENSAB Integer dimension of WSAVE array. LENSAB must be at least  $N/2 + N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

WORK Real work array of dimension at least LENWRK.

LENWRK Integer dimension of WORK array. Must be at least  $2*N+2$ .

#### Output Arguments

R Real output array R. For purposes of exposition, assume R's range of indices is given by  $R(INC:(N-1)*INC)$ .

The output values of R are written over the input values.  
For  $J=1, \dots, N$

$R(J*INC) =$

$$\sum_{N1=1}^N 2.*R(N1*INC)*\text{SIN}(J*N1*\text{PI}/(N+1))/(N+1)$$

IER Integer error return  
= 0 successful exit  
= 1 input parameter LENR not big enough  
= 2 input parameter LENSAB not big enough  
= 3 input parameter LENWRK not big enough  
= 20 input error returned by lower level routine

---

# sintmi

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---

## NAME

SINTMI - initialization routine for SINTMB and SINTMF

## SYNOPSIS

```
SUBROUTINE SINTMI (N, WSAVE, LENSAB, IER)
INTEGER      N, LENSAB, IER
REAL         WSAVE(LENSAB)
```

## DESCRIPTION

FFTPACK 5.0 subroutine SINTMI initializes array WSAVE for use in its companion routines SINTMF and SINTMB. The prime factorization of N together with a tabulation of the trigonometric functions are computed and stored in array WSAVE. Separate WSAVE arrays are required for different values of N.

### Input Arguments

N	Integer length of each sequence to be transformed. The transform is most efficient when N is a product of small primes.
LENSAB	Integer dimension of WSAVE array. LENSAB must be at least $N/2 + N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

### Output Arguments

WSAVE	Real work array with dimension LENSAB, containing the prime factors of N and also containing certain trigonometric values which will be used in routines SINTMB or SINTMF.
-------	--

IER      Integer error return  
= 0 successful exit  
= 2 input parameter LENS AV not big enough  
= 20 input error returned by lower level routine

---

# sintmb

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---

## NAME

SINTMB - real, multiple backward sine fast Fourier transform

## SYNOPSIS

```
SUBROUTINE SINTMB (LOT, JUMP, N, INC, R, LENR, WSAVE, LENSAB,  
1                  WORK, LENWRK, IER)
```

```
INTEGER    LOT, JUMP, N, INC, LENR, LENSAB, LENWRK, IER  
REAL       R(LENR), WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine SINTMB computes the one-dimensional Fourier transform of multiple odd sequences within a real array. This transform is referred to as the backward transform or Fourier synthesis, transforming the sequences from spectral to physical space.

This transform is normalized since a call to SINTMB followed by a call to SINTMF (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

LOT Integer number of sequences to be transformed within array R.

JUMP Integer increment between the locations, in array R, of the first elements of two consecutive sequences.

N Integer length of each sequence to be transformed. The

transform is most efficient when  $N+1$  is a product of small primes.

- INC Integer increment between the locations, in array R, of two consecutive elements within the same sequence.
- R Real array containing LOT sequences, each having length N. R can have any number of dimensions, but the total number of locations must be at least LENR.
- LENR Integer dimension of R array. LENR must be at least  $(LOT-1)*JUMP + INC*(N-1) + 1$ .
- WSAVE Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine SINTMI before the first call to routine SINTMF or SINTMB for a given transform length N. WSAVE's contents may be re-used for subsequent calls to SINTMF and SINTMB with the same N.
- LENSAB Integer dimension of WSAVE array. LENSAB must be at least  $N/2 + N + INT(LOG (REAL(N))) + 4$ .
- WORK Real work array of dimension at least LENWRK.
- LENWRK Integer dimension of WORK array. LENWRK must be at least  $LOT*(2*N+4)$ .

#### Output Arguments

- R Real output array. For purposes of exposition, assume R's range of indices is given by  $R(INC:(LOT-1)*JUMP+N*INC)$ .

The output values of R are written over the input values. For  $I=0, \dots, LOT-1$  and  $J=1, \dots, N$

$R(I*JUMP+J*INC) =$

$$\sum_{N1=1}^N R(I*JUMP+N1*INC) * SIN(J*N1*PI/(N+1))$$

IER      Integer error return  
= 0 successful exit  
= 1 input parameter LENR    not big enough  
= 2 input parameter LENSAB not big enough  
= 3 input parameter LENWRK not big enough  
= 4 input parameters INC,JUMP,N,LOT are not consistent.  
= 20 input error returned by lower level routine

The parameters integers INC, JUMP, N and LOT are consistent if equality  
 $I1*INC + J1*JUMP = I2*INC + J2*JUMP$  for  $I1,I2 < N$   
and  $J1,J2 < LOT$  implies  $I1=I2$  and  $J1=J2$ .

For multiple FFTs to execute correctly, input variables INC, JUMP, N and LOT must be consistent ... otherwise at least one array element mistakenly is transformed more than once.

---



# sintmf

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---

## NAME

SINTMF - real, multiple forward sine fast Fourier transform

## SYNOPSIS

```
SUBROUTINE SINTMF (LOT, JUMP, N, INC, R, LENR, WSAVE, LENSAB,  
1                  WORK, LENWRK, IER)
```

```
INTEGER    LOT, JUMP, N, INC, LENR, LENSAB, LENWRK, IER  
REAL       R(LENR), WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine SINTMF computes the one-dimensional Fourier transform of multiple odd sequences within a real array. This transform is referred to as the forward transform or Fourier analysis, transforming the sequences from physical to spectral space.

This transform is normalized since a call to SINTMF followed by a call to SINTMB (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

LOT	Integer number of sequences to be transformed within array R.
JUMP	Integer increment between the locations, in array R, of the first elements of two consecutive sequences to be transformed.

- N Integer length of each sequence to be transformed. The transform is most efficient when  $N+1$  is a product of small primes.
- INC Integer increment between the locations, in array R, of two consecutive elements within the same sequence.
- R Real array containing LOT sequences, each having length N. R can have any number of dimensions, but the total number of locations must be at least LENR.
- LENR Integer dimension of R array. LENR must be at least  $(LOT-1)*JUMP + INC*(N-1) + 1$ .
- WSAVE Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine SINTMI before the first call to routine SINTMF or SINTMB for a given transform length N. WSAVE's contents may be re-used for subsequent calls to SINTMF and SINTMB with the same N.
- LENSAB Integer dimension of WSAVE array. LENSAB must be at least  $N/2 + N + INT(LOG (REAL(N))) + 4$ .
- WORK Real work array of dimension at least LENWRK.
- LENWRK Integer dimension of WORK array. LENWRK must be at least  $LOT*(2*N+4)$ .

#### Output Arguments

- R Real output array R. For purposes of exposition, assume R's range of indices is given by  $R(0:(LOT-1)*JUMP+(N-1)*INC)$ .

The output values of R are written over the input values. For  $I=0, \dots, LOT-1$  and  $J=1, \dots, N$

$$R(I*JUMP+J*INC) =$$

N

$$SUM \quad 2.*R(I*JUMP+*N1*INC)*SIN(J*N1*PI/(N+1))/(N+1)$$

N1=1

IER Integer error return  
= 0 successful exit  
= 1 input parameter LENR not big enough  
= 2 input parameter LENSAB not big enough  
= 3 input parameter LENWRK not big enough  
= 4 input parameters INC,JUMP,N,LOT are not consistent.

The parameters integers INC, JUMP, N and LOT are consistent if equality  
 $I1*INC + J1*JUMP = I2*INC + J2*JUMP$  for  $I1, I2 < N$   
and  $J1, J2 < LOT$  implies  $I1=I2$  and  $J1=J2$ .

For multiple FFTs to execute correctly, input variables INC, JUMP, N and LOT must be consistent ... otherwise at least one array element mistakenly is transformed more than once.

---

# cosq1i

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---

## NAME

COSQ1I - initialization routine for COSQ1B and COSQ1F

## SYNOPSIS

```
SUBROUTINE COSQ1I (N, WSAVE, LENSAB, IER)
INTEGER          N, LENSAB, IER
REAL             WSAVE(LENSAB)
```

## DESCRIPTION

FFTPACK 5.0 subroutine COSQ1I initializes array WSAVE for use in its companion routines COSQ1F and COSQ1B. The prime factorization of N together with a tabulation of the trigonometric functions are computed and stored in array WSAVE. Separate WSAVE arrays are required for different values of N.

### Input Arguments

N	Integer length of the sequence to be transformed. The transform is most efficient when N is a product of small primes.
LENSAB	Integer dimension of WSAVE array. LENSAB must be at least $2*N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

### Output Arguments

WSAVE	Real work array with dimension LENSAB, containing the prime factors of N and also containing certain trigonometric values which will be used in routines COSQ1B or COSQ1F.
-------	--

IER      Integer error return  
= 0    successful exit  
= 2    input parameter LENS AV not big enough  
= 20   input error returned by lower level routine

---

# cosq1b

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---

## NAME

COSQ1B - real, backward quarter-cosine fast Fourier transform

## SYNOPSIS

```
SUBROUTINE COSQ1B (N, INC, R, LENR, WSAVE, LENSAB, WORK, LENWRK, IER)
```

```
INTEGER      N, INC, LENR, LENSAB, LENWRK, IER  
REAL        R(LENR), WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine COSQ1B computes the one-dimensional Fourier transform of a sequence which is a cosine series with odd wave numbers. This transform is referred to as the backward transform or Fourier synthesis, transforming the sequence from spectral to physical space.

This transform is normalized since a call to COSQ1B followed by a call to COSQ1F (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

- |     |  |
|-----|--|
| N   | Integer number of elements to be transformed in the sequence. The transform is most efficient when N is a product of small primes. |
| INC | Integer increment between the locations, in array R, of two consecutive elements within the sequence.                              |
| R   | Real array of length LENR containing the sequence to be transformed.   |

LENR Integer dimension of R array. LENR must be at least  $INC*(N-1)+1$ .

WSAVE Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine COSQ1I before the first call to routine COSQ1F or COSQ1B for a given transform length N. WSAVE's contents may be re-used for subsequent calls to COSQ1F and COSQ1B with the same N.

LENSAB Integer dimension of WSAVE array. LENSAB must be at least  $2*N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

WORK Real array of dimension LENWRK.

LENWRK Integer dimension of WORK array. LENWRK must be at least N.

#### Output Arguments

R Real output array. For purposes of exposition, assume R's range of indices is given by  $R(0:(N-1)*INC)$ .

The output values of R are written over the input values.  
For  $J=0, \dots, N-1$

$$R(J*INC) =$$

$$\sum_{N1=0}^{N-1} R(N1*INC) * \cos(J*(2*N1+1)*PI/(2*N))$$

WSAVE Contains values initialized by subroutine COSQ1I that must not be destroyed between calls to routine COSQ1F or COSQ1B.

IER Integer error return

- = 0 successful exit
- = 1 input parameter LENR not big enough
- = 2 input parameter LENS AV not big enough
- = 3 input parameter LENWRK not big enough
- = 20 input error returned by lower level routine

---



# cosq1f

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---

## NAME

COSQ1F - real, forward quarter-cosine fast Fourier transform

## SYNOPSIS

```
SUBROUTINE COSQ1F (N, INC, R, LENR, WSAVE, LENSAB, WORK, LENWRK, IER)
```

```
INTEGER      N, INC, LENR, LENSAB, LENWRK, IER  
REAL        R(LENR), WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine COSQ1F computes the one-dimensional Fourier transform of a sequence which is a cosine series with odd wave numbers. This transform is referred to as the forward transform or Fourier analysis, transforming the sequence from physical to spectral space.

This transform is normalized since a call to COSQ1F followed by a call to COSQ1B (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

N            Integer length of the sequence to be transformed. The transform is most efficient when N is a product of small primes.

INC          Integer increment between the locations, in array R, of two consecutive elements within the sequence.

R            Real array of length LENR containing the sequence to be transformed.

LENR Integer dimension of R array. LENR must be at least  $INC*(N-1)+1$ .

WSAVE Real work array with dimension LENSAB. WSAVE's contents must be initialized with a call to subroutine COSQ1I before the first call to routine COSQ1F or COSQ1B for a given transform length N. WSAVE's contents may be re-used for subsequent calls to COSQ1F and COSQ1B with the same N.

LENSAB Integer dimension of WSAVE array. LENSAB must be at least  $2*N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

WORK Real array of dimension LENWRK.

LENWRK Integer dimension of WORK array. LENWRK must be at least N.

#### Output Arguments

R Real output array R. For purposes of exposition, assume R's range of indices is given by  $R(0:(N-1)*INC)$ .

The output values of R are written over the input values.  
For  $J=0, \dots, N-1$

$$R(J*INC) =$$

$$R(0)/N$$

$$+ \sum_{N1=1}^{N-1} 2.*R(N1*INC)*\text{COS}((2*J+1)*N1*PI/(2*N))/N$$

WSAVE Contains values initialized by subroutine COSQ1I that must not be destroyed between calls to routine COSQ1F or COSQ1B.

IER      Integer error return  
= 0 successful exit  
= 1 input parameter LENR    not big enough  
= 2 input parameter LENSAB not big enough  
= 3 input parameter LENWRK not big enough  
= 20 input error returned by lower level routine

---

# cosqmi

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---

## NAME

COSQMI - initialization routine for COSQMB and COSQMF

## SYNOPSIS

```
SUBROUTINE COSQMI (N, WSAVE, LENSAB, IER)
INTEGER      N, LENSAB, IER
REAL         WSAVE(LENSAB)
```

## DESCRIPTION

FFTPACK 5.0 subroutine COSQMI initializes array WSAVE for use in its companion routines COSQMF and COSQMB. The prime factorization of N together with a tabulation of the trigonometric functions are computed and stored in array WSAVE. Separate WSAVE arrays are required for different values of N.

### Input Arguments

N	Integer length of each sequence to be transformed. The transform is most efficient when N is a product of small primes.
LENSAB	Integer dimension of WSAVE array. LENSAB must be at least $2*N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

### Output Arguments

WSAVE	Real work array with dimension LENSAB, containing the prime factors of N and also containing certain trigonometric values which will be used in routines COSQMB or COSQMF.
-------	--

IER      Integer error return  
= 0   successful exit  
= 2   input parameter LENS AV not big enough  
= 20   input error returned by lower level routine

---

# cosqmb

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---

## NAME

COSQMB - real, multiple backward quarter-cosine fast Fourier transform

## SYNOPSIS

```
SUBROUTINE COSQMB (LOT, JUMP, N, INC, R, LENR, WSAVE, LENSAB,  
1                  WORK, LENWRK, IER)
```

```
INTEGER    LOT, JUMP, N, INC, LENR, LENSAB, LENWRK, IER  
REAL       R(LENR), WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine COSQMB computes the one-dimensional Fourier transform of multiple sequences, each of which is a cosine series with odd wave numbers. This transform is referred to as the backward transform or Fourier synthesis, transforming the sequences from spectral to physical space.

This transform is normalized since a call to COSQMB followed by a call to COSQMF (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

LOT Integer number of sequences to be transformed within array R.

JUMP Integer increment between the locations, in array R, of the first elements of two consecutive sequences to be transformed.

N Integer length of each sequence to be transformed. The

transform is most efficient when N is a product of small primes.

- INC      Integer increment between the locations, in array R, of two consecutive elements within the same sequence.
- R        Real array containing LOT sequences, each having length N. R can have any number of dimensions, but the total number of locations must be at least LENR.
- LENR     Integer dimension of R array. LENR must be at least  $(LOT-1)*JUMP + INC*(N-1) + 1$ .
- WSAVE    Real work array with dimension LENSAB. WSAVE's contents must be initialized with a call to subroutine COSQMI before the first call to routine COSQMF or COSQMB for a given transform length N. WSAVE's contents may be re-used for subsequent calls to COSQMF and COSQMB with the same N.
- LENSAB   Integer dimension of WSAVE array. LENSAB must be at least  $2*N + INT(LOG (REAL(N))) + 4$ .
- WORK     Real array of dimension LENWRK.
- LENWRK   Integer dimension of WORK array. LENWRK must be at least  $LOT*N$ .

#### Output Arguments

- R        Real output array. For purposes of exposition, assume R's range of indices is given by  $R(0:(LOT-1)*JUMP+(N-1)*INC)$ .

The output values of R are written over the input values. For  $I=0, \dots, LOT-1$  and  $J=0, \dots, N-1$

$$R(I*JUMP+J*INC) =$$

$$N-1$$

SUM R(I\*JUMP+N1\*INC)\*COS(J\*(2\*N1+1)\*PI/(2\*N))  
N1=0

WSAVE Contains values initialized by subroutine COSQMI that must not be destroyed between calls to routine COSQMF or COSQMB.

IER Integer error return  
= 0 successful exit  
= 1 input parameter LENR not big enough  
= 2 input parameter LENSAB not big enough  
= 3 input parameter LENWRK not big enough  
= 4 input parameters INC,JUMP,N,LOT are not consistent.  
= 20 input error returned by lower level routine

The parameters integers INC, JUMP, N and LOT are consistent if equality

$I1*INC + J1*JUMP = I2*INC + J2*JUMP$  for  $I1, I2 < N$   
and  $J1, J2 < LOT$  implies  $I1=I2$  and  $J1=J2$ .

For multiple FFTs to execute correctly, input variables INC, JUMP, N and LOT must be consistent, otherwise at least one array element mistakenly is transformed more than once.

---



# cosqmf

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---

## NAME

COSQMF - real, multiple forward quarter-cosine fast Fourier transform

## SYNOPSIS

```
SUBROUTINE COSQMF (LOT, JUMP, N, INC, R, LENR, WSAVE, LENSAB,  
1                  WORK, LENWRK, IER)
```

```
INTEGER    LOT, JUMP, N, INC, LENR, LENSAB, LENWRK, IER  
REAL       R(LENR), WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine COSQMF computes the one-dimensional Fourier transform of multiple sequences within a real array, where each of the sequences is a cosine series with odd wave numbers. This transform is referred to as the forward transform or Fourier synthesis, transforming the sequences from spectral to physical space.

This transform is normalized since a call to COSQMF followed by a call to COSQMB (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

**LOT** Integer number of sequences to be transformed within array R.

**JUMP** Integer increment between the locations, in array R, of the first elements of two consecutive sequences to be transformed.

N Integer length of each sequence to be transformed. The transform is most efficient when N is a product of small primes.

INC Integer increment between the locations, in array R, of two consecutive elements within the same sequence.

R Real array containing LOT sequences, each having length N. R can have any number of dimensions, but the total number of locations must be at least LENR.

LENR Integer dimension of R array. LENR must be at least  $(LOT-1)*JUMP + INC*(N-1) + 1$ .

WSAVE Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine COSQMI before the first call to routine COSQMF or COSQMB for a given transform length N. WSAVE's contents may be re-used for subsequent calls to COSQMF and COSQMB with the same N.

LENSAB Integer dimension of WSAVE array. LENSAB must be at least  $2*N + INT(LOG (REAL(N))) + 4$ .

WORK Real array of dimension LENWRK.

LENWRK Integer dimension of WORK array. LENWRK must be at least  $LOT*N$ .

## Output Arguments

R Real output array R. For purposes of exposition, assume R's range of indices is given by  $R(0:(LOT-1)*JUMP+(N-1)*INC)$ .

The output values of R are written over the input values. For  $I=0, \dots, LOT-1$  and  $J=0, \dots, N-1$

$$R(I*JUMP+J*INC) =$$

$$R(I*JUMP)/N$$

$$+ \sum_{N1=1}^{N-1} 2 \cdot R(I \cdot JUMP + N1 \cdot INC) \cdot \cos((2 \cdot J + 1) \cdot N1 \cdot \pi / (2 \cdot N)) / N$$

IER Integer error return

- = 0 successful exit
- = 1 input parameter LENR not big enough
- = 2 input parameter LENSAB not big enough
- = 3 input parameter LENWRK not big enough
- = 4 input parameters INC, JUMP, N, LOT are not consistent.
- = 20 input error returned by lower level routine

The parameters integers INC, JUMP, N and LOT are consistent if equality

$I1 \cdot INC + J1 \cdot JUMP = I2 \cdot INC + J2 \cdot JUMP$  for  $I1, I2 < N$   
and  $J1, J2 < LOT$  implies  $I1 = I2$  and  $J1 = J2$ .

For multiple FFTs to execute correctly, input variables INC, JUMP, N and LOT must be consistent, otherwise at least one array element mistakenly is transformed more than once.

---

# SINQ1I

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---

## NAME

SINQ1I - initialization routine for SINQ1B and SINQ1F

## SYNOPSIS

```
SUBROUTINE SINQ1I (N, WSAVE, LENSAB, IER)
INTEGER      N, LENSAB, IER
REAL         WSAVE(LENSAB)
```

## DESCRIPTION

FFTPACK 5.0 subroutine SINQ1I initializes array WSAVE for use in its companion routines SINQ1F and SINQ1B. The prime factorization of N together with a tabulation of the trigonometric functions are computed and stored in array WSAVE. Separate WSAVE arrays are required for different values of N.

### Input Arguments

N	Integer length of the sequence to be transformed. The transform is most efficient when N is a product of small primes.
LENSAB	Integer dimension of WSAVE array. LENSAB must be at least $2*N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

### Output Arguments

WSAVE	Real work array with dimension LENSAB, containing the prime factors of N and also containing certain trigonometric values which will be used in routines SINQ1B or SINQ1F.
-------	--

IER      Integer error return  
= 0 successful exit  
= 2 input parameter LENS AV not big enough  
= 20 input error returned by lower level routine

---

# sinq1b

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---

## NAME

SINQ1B - real backward quarter-sine fast Fourier transform

## SYNOPSIS

```
SUBROUTINE SINQ1B (N, INC, R, LENR, WSAVE, LENS AV, WORK, LENWRK, IER)
```

```
INTEGER      N, INC, LENR, LENS AV, LENWRK, IER  
REAL        R(LENR), WSAVE(LENS AV), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine SINQ1B computes the one-dimensional Fourier transform of a sequence which is a sine series with odd wave numbers. This transform is referred to as the backward transform or Fourier synthesis, transforming the sequence from spectral to physical space.

This transform is normalized since a call to SINQ1B followed by a call to SINQ1F (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

N            Integer length of the sequence to be transformed. The transform is most efficient when N is a product of small primes.

INC          Integer increment between the locations, in array R, of two consecutive elements within the sequence.

R            Real array of length LENR containing the sequence to be

transformed.

LENR Integer dimension of R array. LENR must be at least  $INC*(N-1)+1$ .

WSAVE Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine SINQ1I before the first call to routine SINQ1F or SINQ1B for a given transform length N. WSAVE's contents may be re-used for subsequent calls to SINQ1F and SINQ1B with the same N.

LENSAB Integer dimension of WSAVE array. LENSAB must be at least  $2*N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

WORK Real work array of dimension at least LENWRK.

LENWRK Integer dimension of WORK array. LENWRK must be at least N.

#### Output Arguments

R Real output array R. For purposes of exposition, assume R's range of indices is given by  $R(INC:N*INC)$ .

The output values of R are written over the input values.  
For  $J=1, \dots, N$

$$R(J*INC) =$$

$$\sum_{N1=1}^N R(N1*INC) * \text{SIN}(J*(2*N1-1)*\text{PI}/(2*N))$$

IER Integer error return  
= 0 successful exit  
= 1 input parameter LENR not big enough  
= 2 input parameter LENSAB not big enough  
= 3 input parameter LENWRK not big enough  
= 20 input error returned by lower level routine

---



# sinq1f

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---

## NAME

SINQ1F - real forward quarter-sine fast Fourier transform

## SYNOPSIS

```
SUBROUTINE SINQ1F (N, INC, R, LENR, WSAVE, LENSAB, WORK, LENWRK, IER)
```

```
INTEGER      N, INC, LENR, LENSAB, LENWRK, IER  
REAL        R(LENR), WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine SINQ1F computes the one-dimensional Fourier transform of a sequence which is a sine series of odd wave numbers. This transform is referred to as the forward transform or Fourier analysis, transforming the sequence from physical to spectral space.

This transform is normalized since a call to SINQ1F followed by a call to SINQ1B (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

N	Integer length of the sequence to be transformed. The transform is most efficient when N is a product of small primes.
INC	Integer increment between the locations, in array R, of two consecutive elements within the sequence.
R	Real array of length LENR containing the sequence to be transformed.

LENR Integer dimension of R array. LENR must be at least  $INC*(N-1)+1$ .

WSAVE Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine SINQ1I before the first call to routine SINQ1F or SINQ1B for a given transform length N. WSAVE's contents may be re-used for subsequent calls to SINQ1F and SINQ1B with the same N.

LENSAB Integer dimension of WSAVE array. LENSAB must be at least  $2*N + INT(LOG (REAL(N))) + 4$ .

WORK Real work array of dimension at least LENWRK.

LENWRK Integer dimension of WORK array. LENWRK must be at least N.

#### Output Arguments

R Real output array R. For purposes of exposition, assume R's range of indices is given by  $R(INC:N*INC)$ .

The output values of R are written over the input values.  
For  $J=1, \dots, N$

$$\begin{aligned}
 R(J*INC) = & \\
 & \sum_{N1=1}^{N-1} (2.*R(N1*INC)*SIN(((2*J-1)*N1*PI/(2*N)))/N \\
 & + ((-1)**(J+1))*R(N*INC)/N
 \end{aligned}$$

IER Integer error return

- = 0 successful exit
- = 1 input parameter LENR not big enough
- = 2 input parameter LENSAB not big enough
- = 3 input parameter LENWRK not big enough
- = 20 input error returned by lower level routine

---

# sinqmi

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---

## NAME

SINQMI - initialization routine for SINQMB and SINQMF

## SYNOPSIS

```
SUBROUTINE SINQMI (N, WSAVE, LENSAB, IER)
INTEGER      N, LENSAB, IER
REAL         WSAVE(LENSAB)
```

## DESCRIPTION

FFTPACK 5.0 subroutine SINQMI initializes array WSAVE for use in its companion routines SINQMF and SINQMB. The prime factorization of N together with a tabulation of the trigonometric functions are computed and stored in array WSAVE. Separate WSAVE arrays are required for different values of N.

### Input Arguments

N	Integer length of each sequence to be transformed. The transform is most efficient when N is a product of small primes.
LENSAB	Integer dimension of WSAVE array. LENSAB must be at least $2*N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

### Output Arguments

WSAVE	Real work array with dimension LENSAB, containing the prime factors of N and also containing certain trigonometric values which will be used in routines SINQMB or SINQMF.
-------	--

IER      Integer error return  
= 0 successful exit  
= 2 input parameter LENS AV not big enough  
= 20 input error returned by lower level routine

---

# sinqmb

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---

## NAME

SINQMB - real, multiple backward quarter-sine fast Fourier transform

## SYNOPSIS

```
SUBROUTINE SINQMB (LOT, JUMP, N, INC, R, LENR, WSAVE, LENSAB,  
1                  WORK, LENWRK, IER)
```

```
INTEGER    LOT, JUMP, N, INC, LENR, LENSAB, LENWRK, IER  
REAL       R(LENR), WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine SINQMB computes the one-dimensional Fourier transform of multiple sequences within a real array, where each of the sequences is a sine series with odd wave numbers. This transform is referred to as the backward transform or Fourier synthesis, transforming the sequences from spectral to physical space.

This transform is normalized since a call to SINQMB followed by a call to SINQMF (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

LOT       Integer number of sequences to be transformed within array R.

JUMP      Integer increment between the locations, in array R, of the first elements of two consecutive sequences to be transformed.

N Integer length of each sequence to be transformed. The transform is most efficient when N is a product of small primes.

INC Integer increment between the locations, in array R, of two consecutive elements within the same sequence.

R Real array containing LOT sequences, each having length N. R can have any number of dimensions, but the total number of locations must be at least LENR.

LENR Integer dimension of R array. LENR must be at least  $(LOT-1)*JUMP + INC*(N-1) + 1$ .

WSAVE Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine SINQMI before the first call to routine SINQMF or SINQMB for a given transform length N. WSAVE's contents may be re-used for subsequent calls to SINQMF and SINQMB with the same N.

LENSAB Integer dimension of WSAVE array. LENSAB must be at least  $2*N + INT(LOG (REAL(N))) + 4$ .

WORK Real work array of dimension at least LENWRK.

LENWRK Integer dimension of WORK array. LENWRK must be at least  $LOT*N$ .

## Output Arguments

R Real output array R. For purposes of exposition, assume R's range of indices is given by  $R(INC:(LOT-1)*JUMP+N*INC)$ .

The output values of R are written over the input values. For  $I=0, \dots, LOT-1$  and  $J=1, \dots, N$

$$R(I*JUMP+J*INC) =$$

```

N
SUM  R(I*JUMP+N1*INC)*SIN(J*(2*N1-1)*PI/(2*N))
N1=1

```

IER Integer error return

- = 0 successful exit
- = 1 input parameter LENR not big enough
- = 2 input parameter LENSAB not big enough
- = 3 input parameter LENWRK not big enough
- = 4 input parameters INC,JUMP,N,LOT are not consistent.
- = 20 input error returned by lower level routine

The parameters integers INC, JUMP, N and LOT are consistent if equality

$I1*INC + J1*JUMP = I2*INC + J2*JUMP$  for  $I1, I2 < N$   
and  $J1, J2 < LOT$  implies  $I1=I2$  and  $J1=J2$ .

For multiple FFTs to execute correctly, input variables INC, JUMP, N and LOT must be consistent ... otherwise at least one array element mistakenly is transformed more than once.

---



# sinqmf

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---

## NAME

SINQMF - real, multiple forward quarter-sine fast Fourier transform

## SYNOPSIS

```
SUBROUTINE SINQMF (LOT, JUMP, N, INC, R, LENR, WSAVE, LENSAB,  
1                  WORK, LENWRK, IER)
```

```
INTEGER    LOT, JUMP, N, INC, LENR, LENSAB, LENWRK, IER  
REAL       R(LENR), WSAVE(LENSAB), WORK(LENWRK)
```

## DESCRIPTION

FFTPACK 5.0 routine SINQMF computes the one-dimensional Fourier transform of multiple sequences within a real array, where each sequence is a sine series with odd wave numbers. This transform is referred to as the forward transform or Fourier synthesis, transforming the sequences from spectral to physical space.

This transform is normalized since a call to SINQMF followed by a call to SINQMB (or vice-versa) reproduces the original array within roundoff error.

### Input Arguments

LOT        Integer number of sequences to be transformed within array R.

JUMP      Integer increment between the locations, in array R, of the first elements of two consecutive sequences to be transformed.

N Integer length of each sequence to be transformed. The transform is most efficient when N is a product of small primes.

INC Integer increment between the locations, in array R, of two consecutive elements within the same sequence.

R Real array containing LOT sequences, each having length N. R can have any number of dimensions, but the total number of locations must be at least LENR.

LENR Integer dimension of R array. LENR must be at least  $(\text{LOT}-1)*\text{JUMP} + \text{INC}*(\text{N}-1) + 1$ .

WSAVE Real work array of length LENSAB. WSAVE's contents must be initialized with a call to subroutine SINQMI before the first call to routine SINQMF or SINQMB for a given transform length N. WSAVE's contents may be re-used for subsequent calls to SINQMF and SINQMB with the same N.

LENSAB Integer dimension of WSAVE array. LENSAB must be at least  $2*N + \text{INT}(\text{LOG}(\text{REAL}(N))) + 4$ .

WORK Real work array of dimension at least LENWRK.

LENWRK Integer dimension of WORK array. LENWRK must be at least  $\text{LOT}*N$ .

## Output Arguments

R Real output array R. For purposes of exposition, assume R's range of indices is given by  $R(\text{INC}:(\text{LOT}-1)*\text{JUMP}+\text{N}*\text{INC})$ .

The output values of R are written over the input values. For  $I=0, \dots, \text{LOT}-1$  and  $J=1, \dots, N$

$$R(I*\text{JUMP}+J*\text{INC}) =$$

$$+ \text{SUM}_{N1=1} (2.*R(I*JUMP+N1*INC)*\text{SIN}(((2*J-1)*N1*PI)/(2*N)))/N$$

$$+ ((-1)**(J+1))*R(I*JUMP+N*INC)/N$$

IER Integer error return

- = 0 successful exit
- = 1 input parameter LENR not big enough
- = 2 input parameter LENSAB not big enough
- = 3 input parameter LENWRK not big enough
- = 4 input parameters INC,JUMP,N,LOT are not consistent.
- = 20 input error returned by lower level routine

The parameters integers INC, JUMP, N and LOT are consistent if equality  
 $I1*INC + J1*JUMP = I2*INC + J2*JUMP$  for  $I1, I2 < N$   
and  $J1, J2 < LOT$  implies  $I1=I2$  and  $J1=J2$ .

For multiple FFTs to execute correctly, input variables INC, JUMP, N and LOT must be consistent ... otherwise at least one array element mistakenly is transformed more than once.

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