New Folder Name Modintsm Program

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FROM: R. WEISS MARCH 18, 1991

TO: LIGO SCIENCE TEAM

CONCERNING: "MODINTSM" PROGRAM TO PROPAGATE MODULATED BEAMS IN AN OPTICAL SYSTEM

CAUTIONARY NOTE: I AM NOT A POLISHED PROGRAMMER SO THIS PROGRAM MAY NOT BE USER FRIENDLY WITHOUT SOME PRACTICE. PEOPLE WHO NOW SEEM COMFORTABLE WITH IT INCLUDE DAVID SHOEMAKER, PETER FRITSCHEL AND RW. IF YOU ARE FACILE WITH PHASOR ALGEBRA DON'T BOTHER WITH THE PROGRAM BECAUSE THAT IS WHAT IT DOES.

END PRODUCT: THE PROGRAM CALCULATES THE INTENSITY IN A MONOCHROMATIC ↓ PLANE WAVE THAT HAS BEEN PHASE MODULATED AND HAS PASSED THROUGH A USER CHOSEN SET OF ELEMENTAL OPTICAL OPERATIONS. THE INTENSITY COMPONENTS ARE GIVEN AT ALL FREQUENCIES REPRESENTED IN THE TIME DEPENDENT INTENSITY WITH THE PHASE REFERENCED TO THE MODULATOR POSITION. THE DIFFERENT FREQUENCY COMPONENTS WOULD BE THE AMPLITUDE OF THE OUTPUT OF MIXERS. BOTH IN PHASE AND QUADRATURE OUTPUTS ARE CALCULATED.

TYPES OF PROBLEMS THAT HAVE BEEN RUN:

1) SIMPLE TEST PROGRAM: DEMONSTRATE REFLECTION LOCKING OF A CAVITY

2) INTENSITIES AT SYMMETRIC AND ANTI SYMMETRIC OUTPUTS OF AN INTENSITY MODULATED MICHELSON INTERFEROMETER

3) SAME AS 2 BUT WITH FABRY-PEROT CAVITIES IN THE INTERFEROMETER ARMS, SINGLE PASS THROUGH ANTISYM. DRIVEN PHASE MODULATORS BETWEEN BEAM SPLITTER AND FRONT CAVITY MIRRORS

4) SAME AS 3 BUT WITH DOUBLE PASS THROUGH PHASE MODULATORS.

5) INTERNAL, TRANSMITTED AND REFLECTED INTENSITY FOR PAIR OF COUPLED CAVITIES IN SERIES. MODULATOR AT INPUT TO COUPLED CAVITY

THEORY OF THE PROGRAM: THE OPERATOR ALGEBRA IS IN PART DEFINED BY THE ACCOMPANYING DESCRIPTION OF THE THEORY OF A RECYCLED, EXTERNALLY MODULATED INTERFEROMETER. THE ONLY STEP NOT SHOWN IS THE COMPLEX MATRIX MULTIPLICATION USED IN CALCULATING THE INTENSITY COMPONENTS AT DIFFERENT FREQUENCIES.

MODINT WAS A RESULT OF DOING THE DESCRIPTION OF THE RECYCLED EXTERNALLY MODULATED INTERFEROMETER. IT BECAME CLEAR TO ME THAT THE ALGEBRA WAS GETTING HOPELESS AND ONE COULD DO THE CALCULATION WITHOUT ALL THE RESTRICTIVE SIMPLIFYING ASSUMPTIONS ON THE COMPUTER. THE IMPORTANT THING WAS TO GET GRAPHICAL OUTPUT

MECHANICS OF DEALING WITH THE PROGRAM

PROGRAM USES: SM GRAPHICS
FORTRAN DOUBLE PRECISION COMPLEX NUMBERS

GIVES: HARDCOPY GRAPHS, TERMINAL GRAPHS
MAKES FILE MODINT.DAT WHICH KEEPS TRACK OF THE INPUT PARAMETERS USED AND PRINTS MAX/MIN VALUES OF IN PHASE AND QUAD. INTENSITIES
IF ASKED WILL MAKE A FILE OF INPUT PARAMETERS THAT CAN BE READ BACK INTO PROGRAM
IF ASKED WILL READ A FILE OF INPUT PARAMETERS

CAN BE RUN WITH LARGE (SLOW RUNNING) OR SMALL (FASTER RUNNING) MATRICES, PRECISION DEPENDS ON THE NUMBER OF MODULATORS AND THE DESIRED ORDER OF THE MODULATION. BE CAREFUL HERE IT DOESN'T TAKE MUCH TO GET SO MANY FREQUENCY COMPONENTS THAT THE PROGRAM OVERRUNS ASSIGNED STORAGE POSITIVE AND NEGATIVE FREQUENCIES ARE CARRIED SEPARATELY UNTIL INTENSITIES ARE CALCULATED.

FOR EXAMPLE: A BEAM MODULATED TO SECOND ORDER WILL COME OUT OF THE MODULATOR WITH 5 COMPONENTS - THE CARRIER AND 4 SIDEBANDS. IF THIS BEAM IS AGAIN MODULATED BY ANOTHER PHASE MODULATOR IT WILL HAVE $(5\times5-1) = 24$ FREQUENCY. AT THE PHOTODETECTOR n m THERE WILL BE 288 FREQUENCIES $\sim (n\times m-1)^2/2$

STEPS:

1) ASKS NAME OF COMPUTER FOR PAINTING ; THE COMPUTER WHICH CONTROLS THE LASER PRINTER

2) ASKS ABOUT NUMBER OF MODULATIONS, IF MORE THAN 2 USED IN SECOND ORDER TELL THE PROGRAM, IT WILL RUN ABOUT 6 TIMES SLOWER.

3) PROGRAM MENU

CAUTION: YOU MUST PAY ATTENTION TO WHETHER REAL OR INTEGER NUMBERS ARE BEING ASKED FOR. IN ITS CURRENT STATE THE WRONG FORMAT WILL CRASH THE PROGRAM

#2 INDEPENDENT PLOT VARIABLE IS THE X AXIS OF ALL PLOTS, SOMETIMES CALLED THE CONTINUOUS VARIABLE, THE NUMBER OF POINTS (1024 MAX) AND THE MAX AND MIN VALUE ARE CHOSEN TO INDICATE WHAT VARIABLE IN THE CALCULATION IS THE INDEPENDENT VARIABLE ONE USES $-1.\times 10^{30}$ IN THE PARAMETER LIST FOR THIS PARAMETER, THIS WILL BECOME CLEARER SOON.

#1 CHOOSE VALUES OF THE PARAMETERS FOR THE CURVES. THIS DOES NOT HAVE TO BE CALLED, THE PROGRAM WILL ALWAYS MAKE A PLOT OF INTENSITY VS INDEPENDENT PLOT VARIABLE. OFTEN ONE WANTS TO CHANGE ANOTHER PARAMETER BESIDES THE INDEPENDENT PLOT VARIABLE, ONE CAN DO THIS DISCONTINUOUSLY WITH UPTO 10 DIFFERENT CURVES. THE NUMBER AND VALUE ASSOCIATED WITH EACH CURVE IS CHOSEN. THE PARAMETER TO BE STEPPED THIS WAY IS CHOSEN LATER BY ASSIGNING IT THE VALUE $1.\times 10^{30}$

#3 CHOOSE THE SEQUENCE OF OPERATIONS SETS UP THE OPTICAL ELEMENTS IN THE CALCULATION. IT TAKES THE MOST TIME TO DO UPTO 100 STEPS ARE ALLOWED. THERE IS NO EASY WAY SHORT OF EDITING THE PARAMETER FILE ONCE IT IS WRITTEN FOR CHANGING THE SEQUENCE OF OPERATIONS AND THEN READING IT BACK IN. IT IS EASY TO CHANGE PARAMETERS CALLED OUT IN ANY OPERATION OF THE SEQUENCE

#4 CHANGE A PARAMETER AFTER SET UP

LETS YOU CHANGE A MISTAKE YOU MADE ON TRY A NEW VALUE FOR A PARAMETER

THE PARAMETER IS IDENTIFIED BY THEIR INTEGERS j K L STEP #, OPERATION #, PARAMETER #

YOU FIND OUT j K L AND THE STEPS YOU HAVE CHOSEN BY

#5 SHOW THE SEQUENCE AND ADOPTED PARAMETERS

THIS WILL LIST STEPS OPERATIONS AND PARAMETERS, THIS LISTING IS ALSO PUT INTO FILE MODINT.DAT

HIT CARRIAGE RETURN WHEN THINGS LOOK THEY ARE STUCK

#9 IS A MEANS OF WRITING THE OPERATIONS AND PARAMETERS INTO A STORED FILE AND ALSO A WAY TO READ SUCH A FILE BACK INTO THE PROGRAM.

IF MANY, SAY MORE THAN 5, ARE USED IN THE CALCULATION IT IS A GOOD IDEA TO MAKE SUCH A STORED FILE - IT IS A WAY OF KEEPING THE CASE YOU HAVE RUN.

#6 RUN THE SEQUENCE — THIS DOES THE CALCULATION YOU ARE ASKED IF YOU WANT TO SEE EXTREMUM RESULTS AS THE CALCULATIONS PROCEEDS, IF YOU CHOOSE THIS YOU WILL HAVE TO HIT CARRIAGE RETURN AFTER EACH WRITE TO THE SCREEN TO KEEP THE CALCULATION GOING.

#8 LIST DETECTED FREQUENCIES CAN ONLY BE DONE ONCE THE CALCULATION HAS BEEN ACCOMPLISHED. IT TELLS YOU WHICH FREQUENCIES ARE REPRESENTED IN THE INTENSITY OF THE BEAM YOU HAVE CHOSEN TO DETECT. UNFORTUNATELY YOU MAY HAVE TO ITERATE BECAUSE YOU HAD ALREADY TO HAVE MADE A CHOICE OF THE FREQUENCY COMPONENTS YOU WANTED TO PLOT BEFORE THE CALCULATION WAS DONE. THIS TO GETS CLEARER AS YOU GO ON.

#7 PLOT → DOES WHAT IT SAYS

#10 RUNS PROGRAM THIS IS THE ORGANIZED WAY TO LEAVE THE PROGRAM SINCE IT CLOSES THE FILE MODINT.DAT

THE OPERATIONS

#1 UNITAMP VERSION

THIS MUST BE CALLED FIRST TO GENERATE A BEAM TO PROPAGATE

PARAMETER $K,1,2$ = 1.0 MAKES A NEW BEAM

$K,1,3$ = 0.0

$K,1,4$ = 0.0

$K,1,5$ = REAL # OF OUTPUT BEAM SAY 1.0

1.0 IS THE NUMBER OF THE FIRST BEAM

#3 MODULATOR

THIS GENERATES THE SIDEBANDS AND CHANGES THE CARRIER USING THE BESSEL EXPANSION FOR PHASE MODULATION

$K,3,2$ MODULATION FREQ

$K,3,3$ Γ

$K,3,4$ HIGHEST MODULATION ORDER, n J_n

$K,3,5$ COSINE EXCITATION

$K,3,6$ SINE EXCITATION

$K,3,7$ Real # OF INPUT AND OUTPUT BEAM TO BE MODULATED

#2 PROPAGATOR

OPTICAL PHASE AND LENGTHS (RF PHASE) ARE KEPT SEPARATELY

FOR EXAMPLE $e^{i(K_0 \ell + K_1 \ell)} = e^{i(\varphi + K_1 \ell)}$ ($K_0 \ell$: OPTICAL, $K_1 \ell$: RF; φ: OPT, $K_1 \ell$: RF)

THIS IS DONE TO KEEP PRECISION OVER LONG PATHS

THIS OPERATION IS THE THING THAT MAKES THE SKELETON OF THE OPTICAL TRAJECTORY

$K,2,2$ φ_{opt}

$K,2,3$ ℓ

$K,2,4$ T $\quad E_{out} = \sqrt{T}\, E_{in}$

$K,2,5$ 0.0 UNLESS YOU WANT TO SCAN CARRIER FREQUENCY

K,2,6 > −1.0 USED IF PAIRED IN ANTIPHASE
K,2,7 > WITH ANOTHER PARAMETER IN THE CALCULATION

K,2,8 Real # OF BEAM BEING PROPAGATED

#4 } OPERATION (PRE PACKAGED) FOR REFLECTION
#5 } OR TRANSMISSION BY A CAVITY

K,4,2	or	K,5,2	$\Delta r/r_{FS}$ } CHOOSE ONE OR THREE MAKE OTHERS = 0.0
K,4,3	or	K,5,3	Δr
K,4,4	or	K,5,4	$\Delta \ell/\lambda$
K,4,5	or	K,5,5	ℓ
K,4,6	or	K,5,6	A_{IN} (100ppm)
K,4,7	or	K,5,7	T_{IN} (100ppm)
K,4,8	or	K,5,8	A_{OUT} (100ppm)
K,4,9	or	K,5,9	T_{OUT} (100ppm)
K,4,10	or	K,5,10	} −1.0 IF PAIRED IN ANTIPHASE WITH ANOTHER PARAMETER
K,4,11	or	K,5,11	REAL # OF INPUT BEAM
K,4,12	or	K,5,12	REAL # OF OUTPUT BEAM (NEW #)!
K,4,13	or	K,5,13	

#6 MIRROR OR BEAM SPLITTER

USED TO SEPARATE BEAMS INPUT BEAM GENERATES BOTH A NEW REFLECTED AND NEW TRANSMITTED BEAM

SPECIFY: SIGNED INTENSITY REFLECTION
THIS IS A TRICK TO GET A MINUS SIGN IN THE REFLECTION COEFFICIENT

$r_{FIELD} = -\sqrt{R_{INT}}$ $t_{FIELD} = (1 - R_{INT} - A_{INT})^{1/2}$ CALCULATED

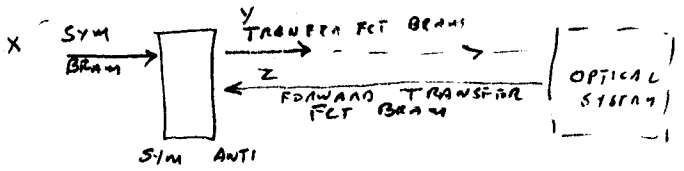
#7 COMBINE BEAMS

USED TO COMBINE BEAMS — TRUE 4 PORT

INPUT BEAM TO BE REFLECTED	A	$r = \pm(1-R)^{1/2}$
INPUT BEAM TO BE TRANSMITTED	B	$t = (1-R-A)^{1/2}$
OUTPUT BEAM ANTISYM	C	$= tB - rA$
OUTPUT BEAM TRANSMITTED	D	$= tB + rA$

#8 OPTICAL FEEDBACK

4 PORT WITH OPTICAL FEEDBACK TO ASYM SIDE

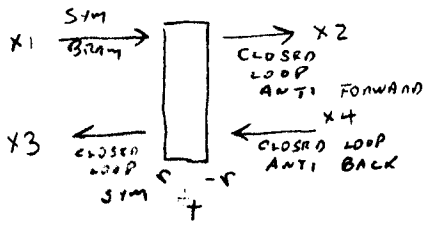


NEED TO MAKE THE TRANSFER FCT BEAM. IT HAS UNITY AMPLITUDE AT EACH FREQUENCY IN SYM BEAM THIS IS DONE BY CALLING UNITAMP AND USING SYM BEAM AS PATTERN FOR FREQUENCIES

UNITAMP

$K_{,1,2} = 0.0$
$K_{,1,3} = 1.0$
$K_{,1,4} = X$
$K_{,1,5} = Y$

THEN PROPAGATE Y THROUGH ENTIRE OPTICAL SYSTEM IT COMES OUT AS BEAM Z



$r = \pm\sqrt{R}$

$t = (1-R-A)^{1/2}$

$X_3 = +X_4 + rX_1$

$X_2 = +X_1 - rX_4$

$X_4 = T_F X_2$

PROGRAM WRITTEN SO THAT THERE SHOULD BE NO NEW SIDE BANDS GENERATED IN OPTICAL SYSTEM, i.e. NO MODULATORS IN OPTICAL SYSTEM, OTHERWISE GET INFINITE # OF NEW FREQUENCIES.
THERE ARE TRICKS AROUND THIS BUT A BETTER WAY WOULD BE TO DO A FULL MODAL ANALYSIS PROGRAM IS NOT DESIGNED FOR THIS

#9 INTENSITY

CHOOSE BEAM # TO CONVERT TO INTENSITY COMPONENTS $I = (E * E^R)$

#10 ↑ EITHER OR ↓ #11 VECTOR PREP. FOR MULTIPLE PARAMETERS CHOOSE FREQ AND PHASE TO PLOT WITH MULTIPLE CURVES OF STEPPED PARAMETER

VECTOR PREP FOR MULTIPLE FREQUENCIES CHOOSE UP TO 10 FREQUENCIES AND PHASES TO PLOT FOR A SINGLE STEPPED PARAMETER