New Folder Name Prototype Development

Some Steps in Development of 40-m Prototype to LIGO Initial Interferometer, Requirements for the Suspended-Mirror Mode Cleaner, and Notes on the Choice of new Modulation Frequency for the present Rigid Mode Cleaner.

(11/14/90:R. Drever)

(Note: This document is a relatively brief initial summary of more extensive considerations, aimed primarily at providing answers to some immediate practical questions. Further clarification of unclear points, and underlying explanations, will be provided.)

A. Functions of the Suspended-Mirror Mode Cleaner:

1. Provides a quiet light beam for the most sensitive region of the main interferometer, isolating the interferometer from fluctuations in the beam arising from the laser or other outside perturbations. Minimum parameters of the beam that the mode cleaner should maintain constant with time include:-

   frequency of the light,
   position, direction, and shape of the beam wavefront,
   polarization state of the beam,
   intensity of the beam (at least over time scales long compared with the period of the modulation waveform).

2. Permits optical components which are known or potential sources of noise to be removed from the sensitive region. By making the mode cleaner have a free spectral range which matches a required modulation frequency, it becomes possible to remove the corresponding modulation Pockels cell to the outside of the system, in front of the mode cleaner. This configuration then provides filtering for the modulation sidebands as well as the laser frequency. Two (or more) modulation frequencies are required for proposed recombined or recycled interferometer configurations. It is desirable that the mode cleaner can be used for such configurations when they are tested in the 40-m system, and for this its length should allow at least two non-interfering frequencies to be transmitted.

   Use of a ring cavity configuration for the mode cleaner opens further possibilities for significantly simplifying the critical part of the interferometer, by allowing removal of the Faraday rotators, polarizers, and quarter-wave plates. This enables the sensitive part of the interferometer to be very simple, and free of several potential sources of noise present in existing systems. Previous experience with ring cavities has been encouraging (and it was for the ring cavities of laser gyros that super mirrors were originally developed). Because of the simple configurations they made possible, ring cavities were used for the main interferometer arms in early interferometers built at Caltech (and also at Glasgow). Phase sensitivity of the same order as that envisaged with planned mode cleaners was demonstrated.

B. Experimental Requirements.

1. The practical requirements for the mode cleaner are clarified by considering the sequence of experiments likely to be carried out with the 40-m system. A possible

sequence of steps leading from the present existing configuration is outlined below, and some of the corresponding optical configurations are illustrated. This series of main steps is chosen to allow a systematic exploration, discovery and investigation of potential noise sources which may limit performance, and enable them to be eliminated in an effective way. The actual sequence would of course vary according to the results obtained, but the steps shown illustrate the critical functions of the mode cleaner, and the simplifications made possible by use of a ring cavity.

2. The recombination system shown in this sequence is the differential-tuned system proposed recently, as this seems compatible with the present vacuum system, and also seems promising for the future. A mode cleaner capable of transmitting two modulation frequencies suitable for this or other systems is proposed. For avoidance of interference along with minimum mode cleaner length a ratio of 2:3 between the frequencies is proposed. A number of possible frequencies satisfying this requirement is shown in the Table (D). These are chosen also to satisfy the relation to the arm length of the nominal 40-m arms suitable for a differential-tuned system. (Not all the quantities listed are relevant at this point, but their meaning is as follows: F0 is the main (differential) modulation frequency; F1 is the modulation frequency used for locking to the laser wavelength; and n1 is the ratio of F1 to the free spectral range of a nominal 40-m arm. Similar frequencies and mode cleaner lengths would apply for other optical configurations.)
3. The proposed sequences of experimental steps involves use of the suspended mode cleaner together with the present rigid mode cleaner at some stages. The combination of two mode cleaners is likely to be the simplest way to eliminate some types of Pockels cell noise. (It has also been proposed as a way of coping with high optical power in future systems.)
4. The practical construction of a 3-mirror ring mode cleaner can be very similar to that of a 2-mirror mode cleaner. In either case, the mirrors can each have an OSEM system for rough angular and position control (equivalent to present "local controls" in the 40-m arms). Fine angular control (equivalent to "global control") is by optical levers spanning the length of the system, with the two plane mirrors at one end of the ring controlled by a single laser beam reflecting of each of them in turn. The intermediate beam emerging after one reflection at a plane mirror is also monitored to define the output beam direction.

C. Some Steps in Development for the LIGO Initial Interferometer and corresponding optical configurations in 40-m prototype.

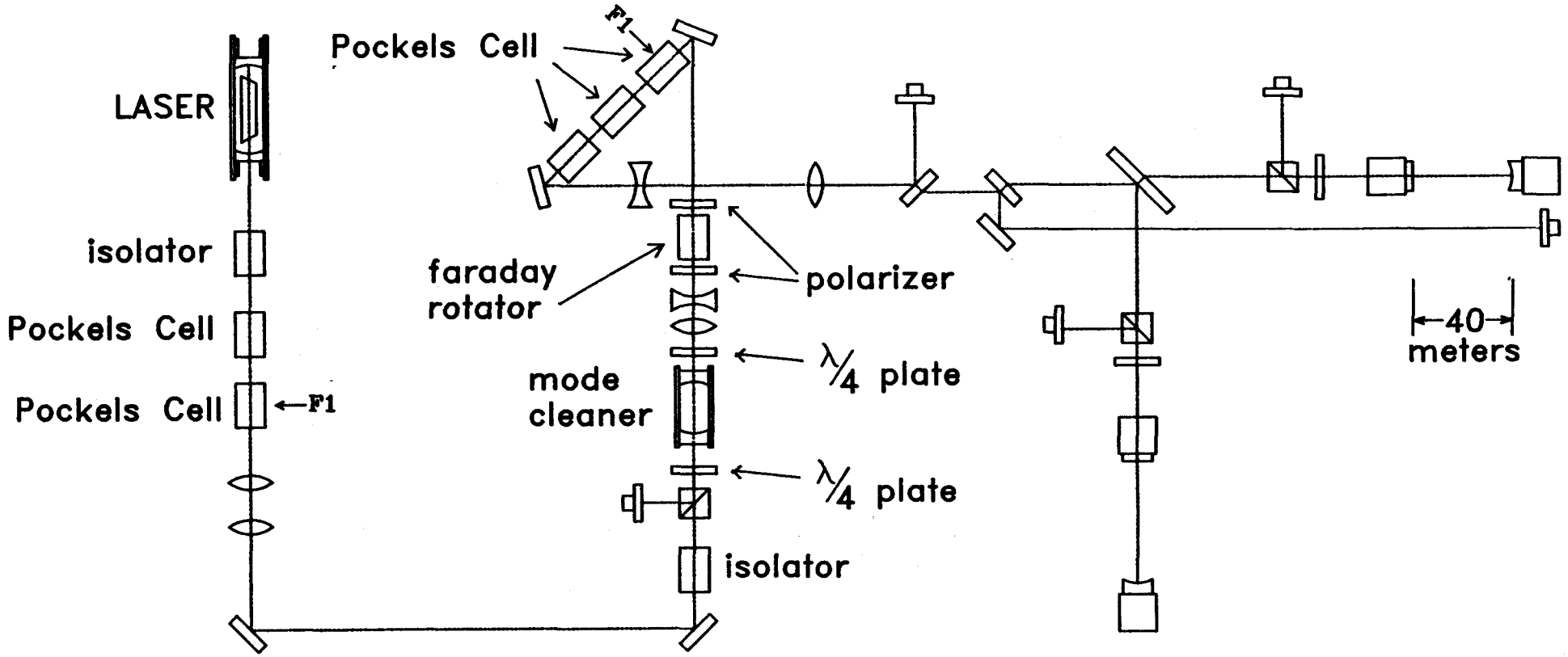
The earlier steps listed (numbered 0 to 7) are practicable within the present vacuum chambers for the main 40-m interferometer. Steps 8 and 9 are likely to require the rebuilt 40-m chambers and beam tubes.

Step Number—

0. Present state. Feed-around loop in use, but internal phase correcting Pockels cells still in place.
1. Remove phase correcting Pockels cells between the mode cleaner and beamsplitter.
2. Change modulation frequency for mode cleaner to a frequency F2, different from the main interferometer frequency F1 = 12.33 MHz, to eliminate disturbance of the main system by RF amplitude modulation of the light leaving the mode cleaner. If convenient at this stage, two monitoring pick-off plates can also be removed and replaced by a reflection from the back of the beamsplitter. To simplify the drawings, this is illustrated, but it is not a critical step.
3. Replace the short rigid mode cleaner and the internal Faraday isolator by a ring mode cleaner with suspended mirrors (same modulation frequency F2).
4. Move the main RF Pockels cell from its present position between the mode cleaner and the beamsplitter to a position in front of the mode cleaner.

   (Note: the following steps, 5 and 6, would be interchanged if sensitivity at step 4 reaches shot noise level for the available light.)
5. Put the short rigid mode cleaner in front of the RF Pockels cell for the ring mode cleaner. (Modulation frequency F3).
6. Implement recombination (differential tuned system) by replacing the circulators in front of 40-m arms by pickoff plates, and adding the recombination modulation frequency F0 to the main RF Pockels cell.
7. Add an output mode cleaner (This will reduce scattering effects, and also is required for some modulation techniques.).
8. Add a broadband recycling mirror and the servo.
9. Add a dual recycling mirror and servo control for it.

STEP 0. Present system.



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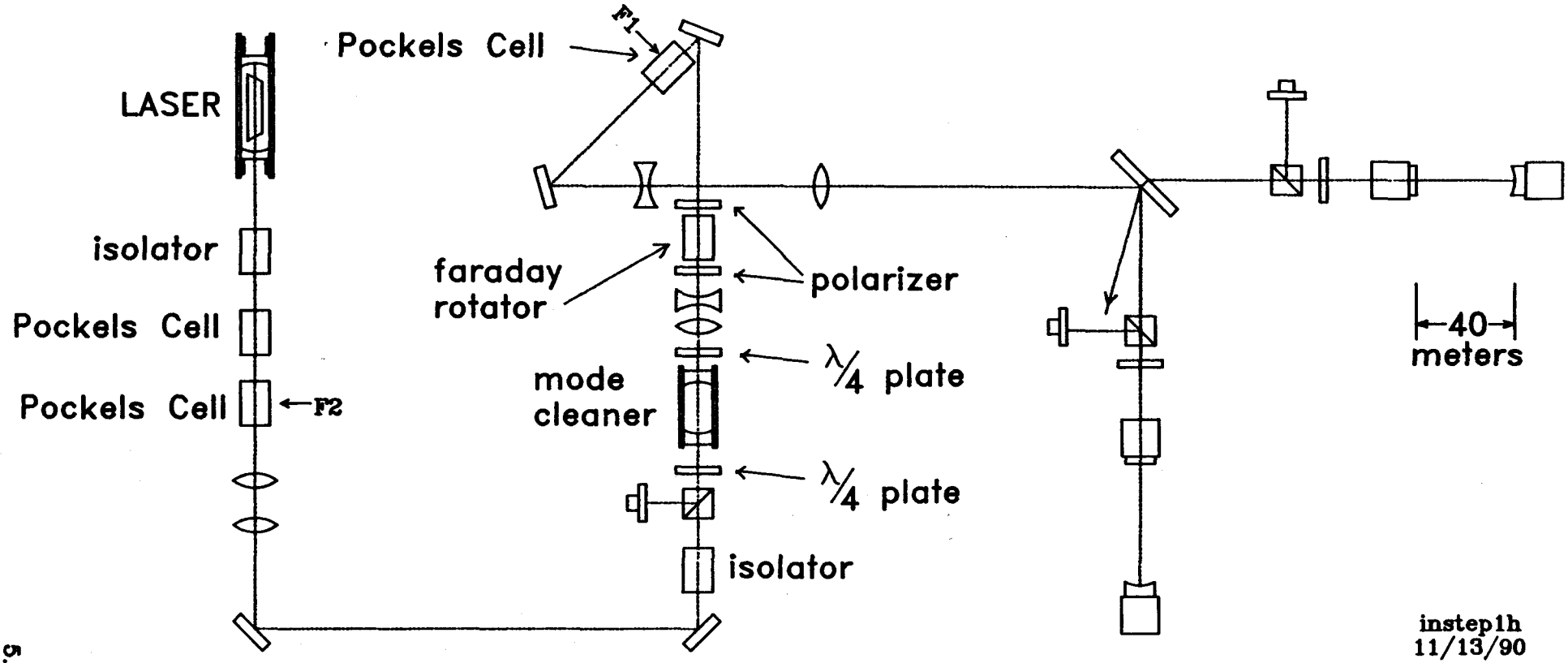
STEP 2. Remove 2 Pockels cells, replace 2 pickoffs, add F2.



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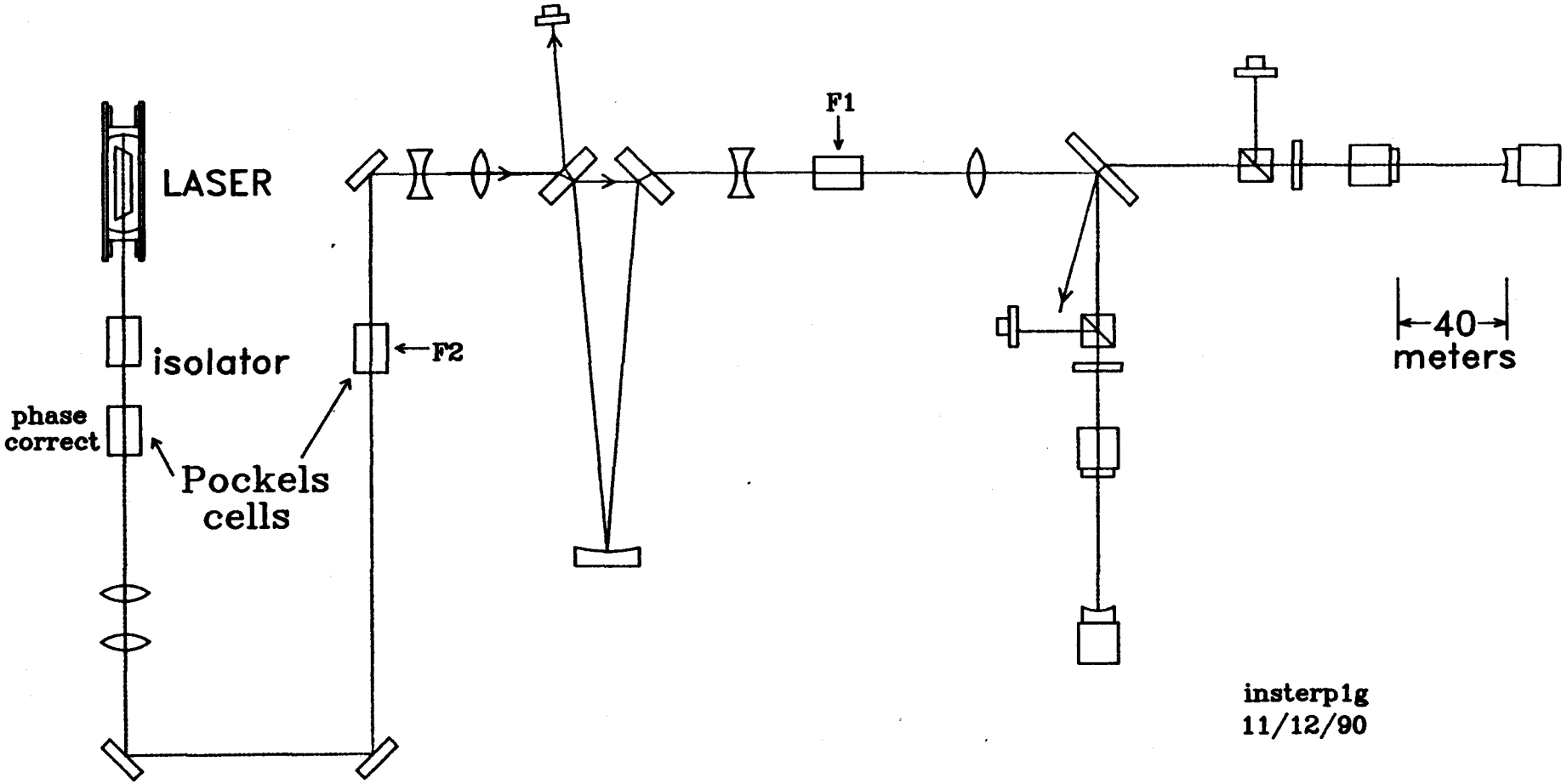
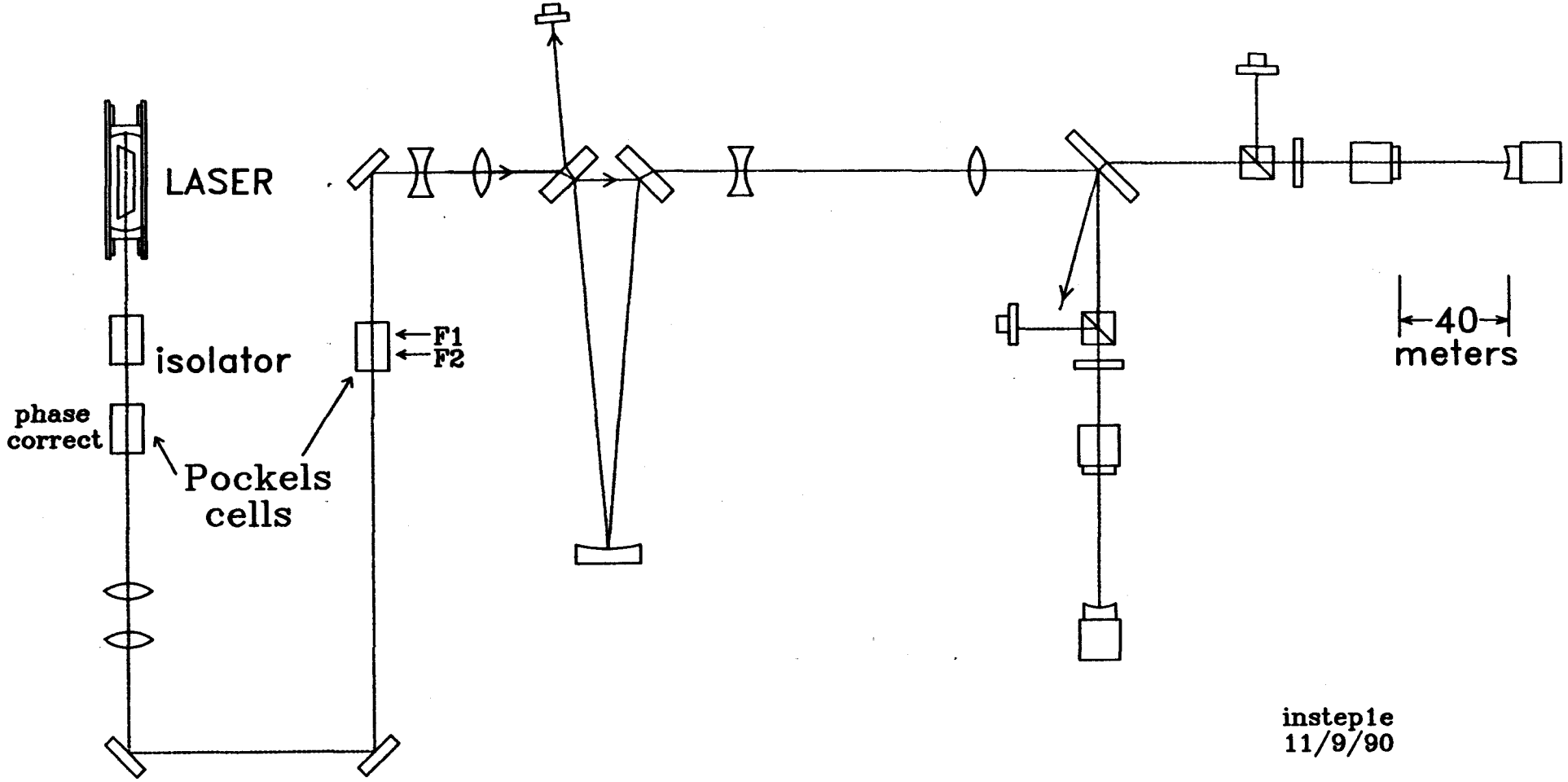
STEP 3. REPLACE Rigid mode cleaner by suspended one.



STEP 4. CLEAR OUT POCKELS CELL from sensitive region



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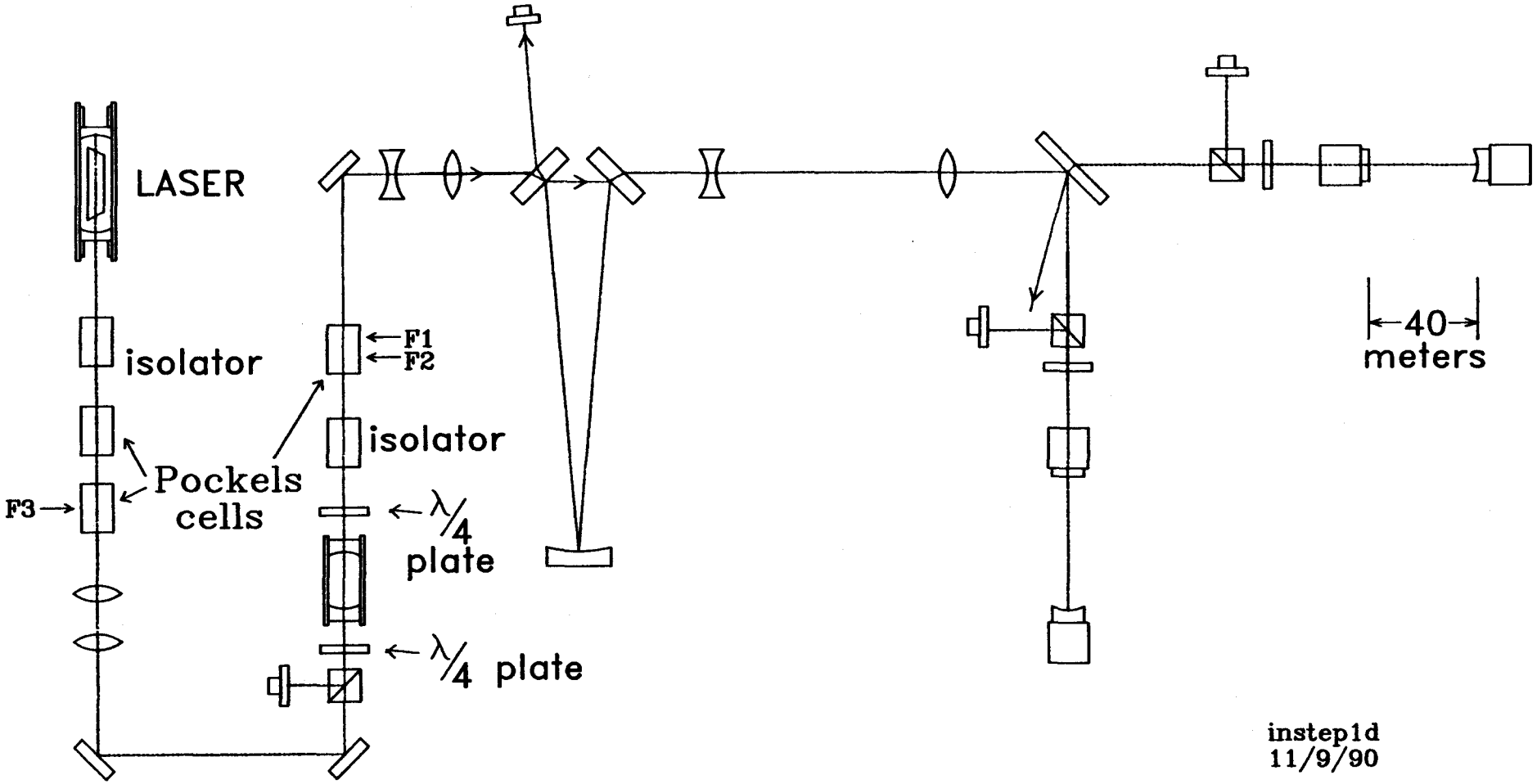
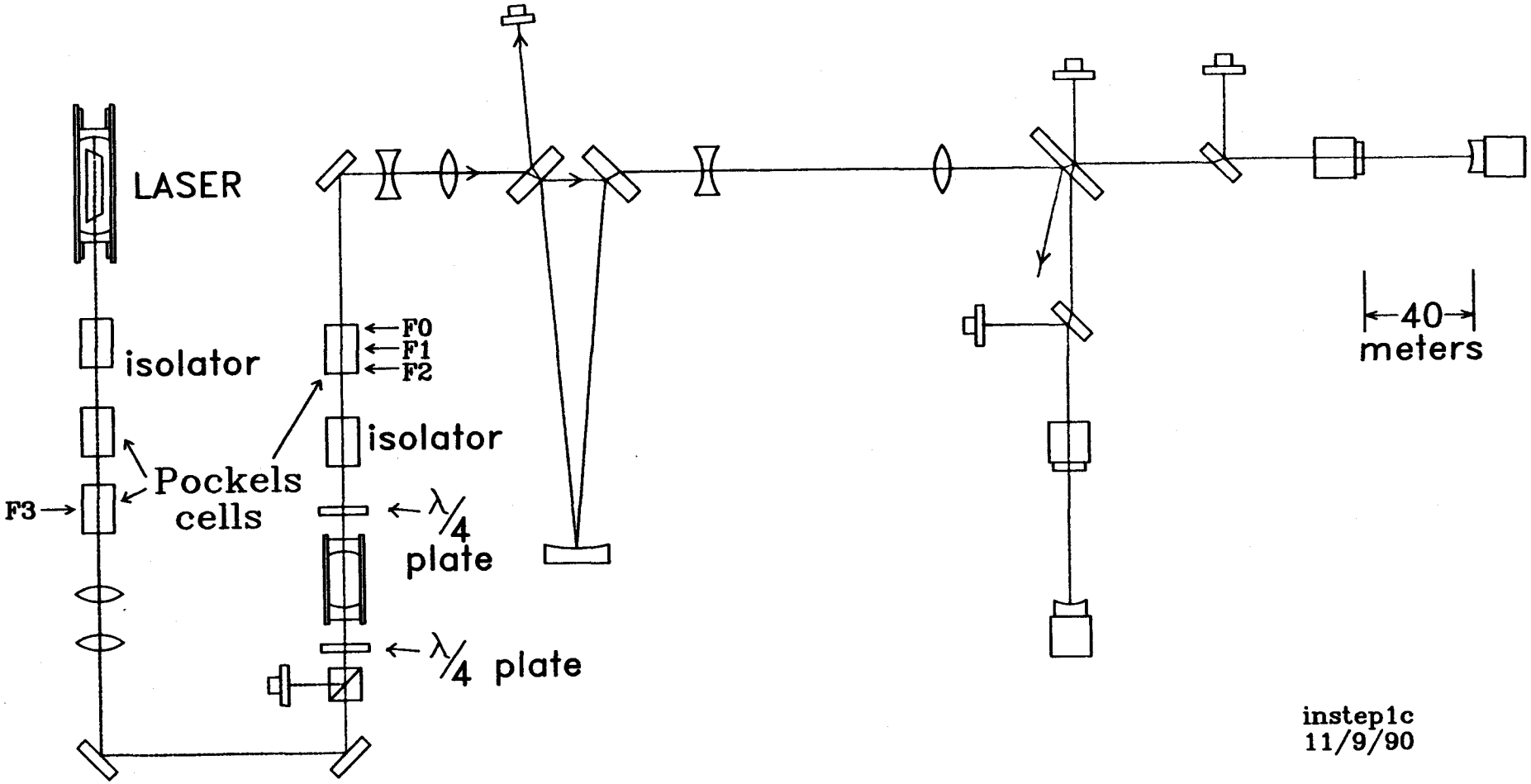
STEP 5. RIGID MODE CLEANER guarding Pockels cell



STEP 6. RECOMBINATION.



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D. Choice of Modulation Frequencies for Mode Cleaners and Arms in the present configuration and near-future ones.

The 40-m interferometer currently operates with a single modulation frequency of 12.33 MHz, both for locking the interferometer arms and for locking the laser to the mode cleaner. This frequency was chosen to be high enough for laser noise to be low; low enough to avoid noticeable dielectric heating of the Pockels cells; and free from strong sources of local interference. It has been found that transmission of modulation products by the mode cleaner can affect the coherent demodulation - at the same frequency - of the signals from the main interferometer arms. Use of different modulation frequencies for main interferometer and mode cleaner avoids this. In choosing a new mode cleaner frequency it is worth considering requirements of developments of the interferometer such as those outlined in section C above, so that unnecessary rebuilding of equipment is avoided.

For future recombined or recycled interferometers four or more modulation frequencies are likely to be required. In the systems shown in section C, and also in others, the main mode cleaner is used to filter the sidebands for two modulation frequencies used in the interferometer itself. For this to be practicable, each modulation frequency has to be a multiple of the free spectral range of the mode cleaner. The simplest ratio between the two modulation frequencies which would avoid cross-coupling problems is 2:3, and, if one frequency is given, this defines a minimum mode cleaner length. For the recombination scheme shown, the differential-tuned system, there is also a requirement that one modulation frequency is a multiple of the free spectral range of an interferometer arm. A list of frequencies satisfying these conditions, and the corresponding lengths for the suspended-mirror mode cleaner, is given in Table 1.

Table 1 — Compatible Pairs of Modulation Frequencies F0 and F1 and Corresponding Lengths of Main Mode Cleaner.

These frequencies apply for interferometer arm lengths assumed within 1 cm of those in the present system, taken as 39.40 m.

The list is in order of increasing frequency, and decreasing mode cleaner length. The higher frequency of each pair is listed first.

Frequencies (MHz)				Mode Cleaner Length (m)	n1	F0/F1	Notes
11.4	(F1)	7.6	(F0)	39.4	3	2/3	(Same as nominal 40-m arm)
15.2	(F1)	10.2	(F0)	29.6	4	2/3	
17.1	(F0)	11.4	(F1)	26.3	3	3/2	
19.0	(F1)	12.7	(F0)	23.6	5	2/3	(F0 near present modulation freq.)
22.9	(F0)	15.3	(F1)	19.7	4	3/2	
22.9	(F1)	15.3	(F0)	19.7	6	2/3	
28.6	(F0)	19.0	(F1)	15.8	5	2/3	
34.3	(F0)	22.9	(F1)	13.1	6	2/3	

Frequencies which are on the above list are the ones useful for the main interferometer in later stages. The two further modulation frequencies needed for locking the mode cleaners themselves are not required to bear a precise relationship to those on the list, but should be chosen to avoid having beat frequencies within the range of the servo systems, and different from one another.

E. Preferred Choice of Frequencies.

A choice which looks particularly suitable at present is 19.0 MHz and 12.7 MHz for the related frequencies, with the other two frequencies in quiet regions for local interference within about 1 MHz of 15.2 and 8.7 MHz, respectively. The corresponding mode cleaner length is 23.6 meters, which is reasonably convenient.

A major advantage of this choice is that one main frequency, 12.7 MHz, is close enough to our present working frequency to make retuning of existing equipment relatively simple. This would be a useful main modulation frequency in the future.

With this choice of main frequency, a good choice for the new modulation frequency required immediately for the present mode cleaner would be 19.0 MHz. This choice could be doubly useful - It would make it practicable later to implement the differential-tuned recombination system with minimum building of further equipment, and it would let us confirm early that operation at this frequency does not give any problems with dielectric

heating or any other secondary effects in a real interferometer. With this confirmed we could be confident also about the two other frequencies proposed, which are both lower.

It is therefore concluded that this frequency should be a good one for the new modulation system of the present mode cleaner, and a useful one to have electronics for. The precise frequency would be the 5th harmonic of the free spectral range of one of the nominal 40-m arms, which is close to 19.04 MHz.