**ΕΡΓΑΣΤΗΡΙΟ ΟΠΤΟΗΛΕΚΤΡΟΝΙΚΗΣ**

**(ΗΡΥ412 & ΗΡΥ607)**

**Logo

Description automatically generated**

***ΑΝΑΦΟΡΕΣ ΓΙΑ ΤΗΝ ΔΙΕΞΑΓΩΓΗ ΤΩΝ***

***ΕΡΓΑΣΤΗΡΙΑΚΩΝ ΑΣΚΗΣΕΩΝ 1 ΕΩΣ 4***

ΟΜΑΔΑ: 2 (Πάγκος)

|  |  |
| --- | --- |
| ΟΝΟΜΑΤΕΠΩΝΥΜΟ | ΑΜ |
| Ελληνιτάκης Αντώνιος Ραφαήλ | 2017030118 |
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ΧΕΙΜΕΡΙΝΟ ΕΞΑΜΗΝΟ 2021-2022

**ΠΕΙΡΑΜΑΤΙΚΗ ΑΣΚΗΣΗ 1 : ΚΑΤΑΣΚΕΥΗ ΟΛΟΚΛΗΡΩΜΕΝΗΣ ΠΗΓΗΣ LASER ΗΜΙΑΓΩΓΟΥ**

**Βήμα 1**

Υλοποιήσαμε, αρχικά, το ζητούμενο κύκλωμα του βήματος 1 της εργαστηριακής άσκησης σε breadboard (όπως φαίνεται και στo Fig. 1 ). Στη συνέχεια ελέγξαμε αν το κύκλωμα λειτουργεί κανονικά, δηλαδή μεταβολή της αντίστασης του ποτενσιόμετρου συνεπάγεται με μεταβολή του ρεύματος και άρα μεταβολή της φωτεινότητας του LED. Αυτό συμβαίνει, διότι όσο μειώνεται η τιμή της αντίστασης του ποτενσιόμετρου, τόσο αυξάνεται η τάση στο σημείο Α. Επομένως αυξάνεται και το ρεύμα που διέρχεται από την αντίσταση R1, το οποίο λόγω της μεγάλης αντίστασης του τελεστικού θα περάσει προς τον εκπομπό. Όταν το τρανζίστορ λειτουργεί στην ενεργό περιοχή το ρεύμα του εκπομπού είναι ίσο με του συλλέκτη και στο συγκεκριμένο κύκλωμα με το ρεύμα που διέρχεται από το LED. Ως φυσικό επακόλουθο, όσο περισσότερο ρεύμα διαρρέει το LED τόσο πιο φωτεινό γίνεται.

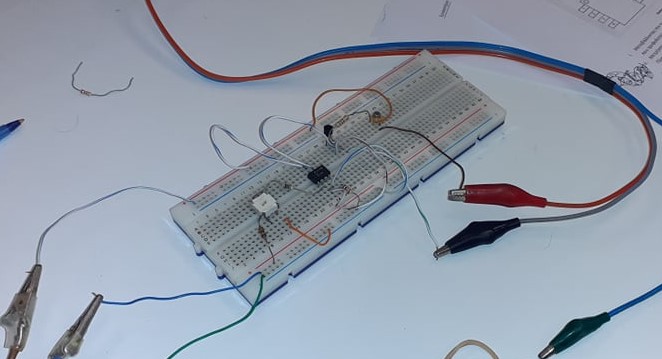


Fig. 1 Εργαστηριακό κύκλωμα σε breadboard

Κατόπιν, μεταβάλλοντας την τιμή του ποτενσιόμετρου υπολογίσαμε την ελάχιστη και την μέγιστη τιμή του ρεύματος, με την οποία τροφοδοτείται το LED. Για τις εκάστοτε τιμές αντιστάσεων που ζητήθηκαν προκύπτει ο ακόλουθος πίνακας:

Πίνακας 1 : Ελάχιστο και μέγιστο ρεύμα μεταβάλλοντας την R1

|  |  |  |
| --- | --- | --- |
| R1 (Ω) | IMIN | IMAX |
| 270 | 30 μA | 25 mA |
| 820 | 8 μA | 11 mA |

Στη συνέχεια, μετρήθηκε η τάση στο σημείο Α (VA) για τις δοθείσες τιμές ρεύματος του LED. Οι μετρήσεις παρουσιάζονται στον Πίνακας 2.

Πίνακας 2: Τάση στο σημείο Α με μεταβλητές τιμές ρεύματος LED

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| I LED (mA) | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 |
| VA (R1 = 270Ω) | 0 | 0.5 | 1.1 | 1.65 | 2.2 | 2.72 | 3.3 | 3.77 | 4.3 | 4.8 | 5.5 | 5.9 | 6.4 |
| VA (R1 = 820Ω) | 0 | 1.7 | 3.4 | 5.1 | 6.8 | 8.4 | 9.7 | - | - | - | - | - | - |

Ακολούθως, παρουσιάζονται τα διαγράμματα ILED σε συνάρτηση με την τάση VA για τις δυο τιμές της αντίστασης R1.

Fig. 2: Διαγράμματα ρεύματος LED συναρτήσει της τάσης στο σημείο Α

Σύμφωνα με τα προαναφερθέντα διαγράμματα (Fig. 2), είναι εύκολο να διαπιστωθεί μια γραμμική σχέση μεταξύ της τάσης VA και του ρεύματος που διαρρέει το LED, που συμφωνεί με την θεωρία. Αυτό συμβαίνει, καθώς στο κύκλωμα χρησιμοποιείται ένας τελεστικός ενισχυτής ως πηγή σταθερού ρεύματος ελεγχόμενου από τάση, ο οποίος συμπεριφέρεται γραμμικά. Με άλλα λόγια στον τελεστικό ενισχυτή η έξοδος είναι ανάλογη της εισόδου, δηλαδή Vout = A \* Vin , όπου Α το κέρδος. Το τρανζίστορ, επίσης, λόγω της ορθά πολωμένης επαφής βάσης-εκπομπού, ενισχύει το ρεύμα εξόδου του τελεστικού οδηγώντας το στο συλλέκτη και τελικά στο LED. Επομένως, το ρεύμα που διαρρέει το LED είναι ανάλογο της τάσης VA.

Παρατηρείται, ακόμα, ότι όσο αυξάνεται η τιμή της τάσης VA τόσο αυξάνεται και η τιμή του ρεύματος ILED. Γεγονός αναμενόμενο, γιατί η τιμή του ρεύματος του LED είναι ελάχιστη όταν η αντίσταση του ποτενσιόμετρου είναι η μέγιστη. Αυτό είναι απόρροια του ότι το ρεύμα που διέρχεται από την αντίσταση R1 είναι μικρό, όταν η αντίσταση του ποτενσιόμετρο είναι μεγάλη. Έτσι, το συγκεκριμένο ρεύμα φτάνει στον εκπομπό του τρανζίστορ, θεωρώντας ότι ο τελεστικός ενισχυτής έχει άπειρη αντίσταση, και έπειτα περνάει στον συλλέκτη. Το ρεύμα που διέρχεται από το LED είναι ίσο με το ρεύμα του συλλέκτη, οπότε έχει και αυτό μικρή τιμή. Επομένως, μπορούμε να πούμε ότι αύξηση της VA προκαλεί αύξηση του ILED, διότι η VA επηρεάζει ουσιαστικά την ποσότητα του ρεύματος που θα φτάσει τελικά στο LED, όπως εξάλλου παρατηρήθηκε και από τα διαγράμματα. Για αυτό τον λόγο προκύπτει από το πείραμα ότι για R1 = 820Ω η τιμή του μέγιστου ρεύματος του LED είναι μικρότερη από την αντίστοιχη για R1 = 270Ω.

Το πράσινο LED έχει μικρότερο μήκος κύματος από το κόκκινο και επομένως μεγαλύτερο ενεργειακό χάσμα, αφού ισχύει ότι . Ως αποτέλεσμα η διαφορά δυναμικού που πρέπει να εφαρμόσουμε είναι μεγαλύτερη, ώστε τα ηλεκτρόνια να αποκτήσουν ενέργεια ίση με αυτή του ενεργειακού χάσματος. Με άλλα λόγια, το εξωτερικό δυναμικό που πρέπει να δοθεί στο LED για να διεγερθεί ένα ηλεκτρόνιο από την ζώνη σθένους στην ζώνη αγωγιμότητας, ώστε με την αυθόρμητη εκπομπή να παραχθούν φωτόνια, είναι μεγαλύτερο στο πράσινο LED, λόγω του μεγαλύτερου ενεργειακού χάσματος. Δηλαδή απαιτείται περισσότερο ρεύμα, ώστε να διεγερθούν τα ηλεκτρόνια στη ζώνη αγωγιμότητας, με αποτέλεσμα μεγαλύτερο ενεργειακό χάσμα να χρειάζεται μεγαλύτερη τιμή εξωτερικής εφαρμοζόμενης τάσης. Επομένως, συμπεραίνουμε ότι όσο αφορά το διάγραμμα, αν αντί για κόκκινο είχαμε πράσινο LED, θα συνεχιζόταν να υπάρχει η γραμμική σχέση μεταξύ της τάσης VA και του ρεύματος ILED με την διαφορά ότι οι τιμές της τάσης θα ήταν υψηλότερες στην περίπτωση του πράσινου LED.

**Βήμα 2**

Στο δεύτερο μέρος της πρώτης πειραματικής άσκησης υπολογίσθηκε, αρχικά, η τιμή της αντίστασης R1 ώστε να μπορεί να οδηγηθεί το laser στα 25mA. Ο υπολογισμός έγινε με βάση την παρακάτω.

(1)

Προκύπτει ότι

Ακολούθως, αφού μηδενίστηκε το ρεύμα στο LED, αντικαταστάθηκε με την δίοδο laser και μετρήθηκε η ισχύ της εξόδου με την χρήση του φωτόμετρου. Οι ζητούμενες τιμές που μετρήθηκαν για την εκάστοτε τιμή ρεύματος του LED είναι σε dBm (Πίνακας 3) και η μετατροπή τους σε mWatt γίνεται μέσω της ).

(2)

Πίνακας 3 : Ισχύς εξόδου

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| I LD (mA) | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 |
| Ισχύς (P)  (dBm) | 0 | -40.2 | -31.15 | -27.7 | -26.2 | -25.9 | -23.7 | -22.4 | -21.63 | -20.1 | -15.2 | -13.85 | -4.5 |
| Ισχύς (P)  (mW) | 0 | 9.55 \*10-5 | 7.68 \*10-4 | 0.0017 | 0.0024 | 0.0026 | 0.0043 | 0.0058 | 0.0069 | 0.01 | 0.03 | 0.04 | 0.4 |

Στη συνέχεια, παρατίθεται το διάγραμμα ILD σε συνάρτηση με την ισχύ P.

Fig. 3: Διάγραμμα ρεύματος LED συναρτήσει Ισχύς

Η καμπύλη που προέκυψε έχει παρόμοια μορφή με την αντίστοιχη θεωρητική. Το ρεύμα κατωφλίου, αρχικά, για την έναρξη του lasing είναι περίπου στα 20mA, γιατί από αυτή την τιμή και έπειτα αυξάνεται σημαντικά η ισχύς εξόδου. Παρατηρείται, επίσης, ότι για τιμές ρεύματος μικρότερες από το ρεύμα κατωφλίου η δίοδος συμπεριφέρεται σαν LED. Στην συγκεκριμένη περίπτωση εκπέμπει ασύμφωνη, μη κατευθυντική και μικρής έντασης μονοχρωματική ακτινοβολία. Αυτό συμβαίνει διότι τα φωτόνια που εκπέμπονται δεν είναι συμφασικά, λόγω του ότι η αυθόρμητη εκπομπή υπερισχύει της εξαναγκασμένης. Για τιμές ρεύματος μεγαλύτερες από την τιμή του ρεύματος κατωφλίου η δίοδος συμπεριφέρεται ως laser, καθώς γίνεται αντιστροφή πληθυσμών και τα φωτόνια είναι σε συμφωνία φάσης. Η εκπεμπόμενη ακτινοβολία σε αυτή την περίπτωση είναι μονοχρωματική, κατευθυντική και έχει μεγάλη ένταση. Για κάποιες τιμές ρεύματος, κοντά στο κατώφλι αντιστροφής, οι δυο προαναφερθείσες περιπτώσεις συνυπάρχουν και έτσι η δίοδος έχει χαρακτηριστικά LED και laser.

**ΠΕΙΡΑΜΑΤΙΚΗ ΑΣΚΗΣΗ 2 : ΦΩΤΟΤΡΑΝΖΙΣΤΟΡ ΚΑΙ ΧΡΗΣΗ ΤΟΥ ΣΤΗΝ ΜΕΤΡΗΣΗ ΤΗΣ ΣΥΓΚΕΝΤΡΩΣΗΣ ΔΙΑΛΥΜΑΤΟΣ**

**Βήμα 1**

Υλοποιήσαμε, αρχικά, το ζητούμενο κύκλωμα του βήματος 1 της εργαστηριακής άσκησης σε breadboard (όπως φαίνεται και στο Fig. 4).

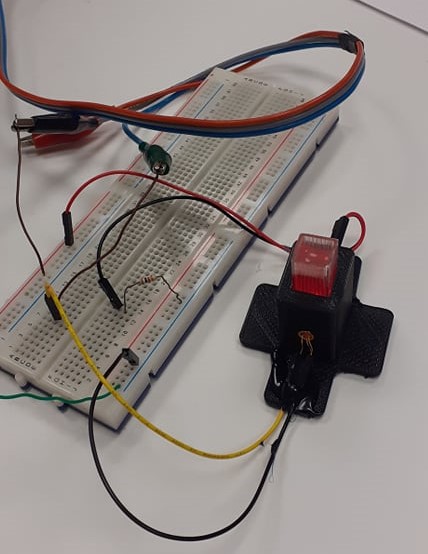


Fig. 4: Δεύτερο εργαστηριακό κύκλωμα σε breadboard

**Βήμα 2**

Κατόπιν, μελετήθηκε η γραμμικότητα της απόκρισης του φωτοτρανζίστορ και της φωτομετρικής βαθμονόμησής του. Μετρήσαμε, αρχικά, το ρεύμα σκότους καλύπτοντας την φωτοευαίσθητη περιοχή του τρανζίστορ με ένα χαρτί και προέκυψε ότι . Έπειτα, μεταβάλλοντας την τιμή της αντίστασης αλλάζει η ένταση του LED και καταγράφουμε το ρεύμα του συλλέκτη του φωτοτρανζίστορ (iPT) για τις διάφορες τιμές αντίστασης R. Στη συνέχεια υπολογίστηκε και το ζητούμενο ρεύμα icorr , όπως παρουσιάζεται στον Πίνακας 4.

Πίνακας 4: Τιμές ρευμάτων για τα διαφορετικά R

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| R(kΩ) | 1.0 | 2.2 | 3.9 | 5.1 | 6.2 | 7.5 | 9.1 | 10 |
| Ισχύς (μW) | 8.09 | 4.21 | 2.33 | 1.56 | 1.11 | 0.9 | 0.73 | 0.7 |
| IPT (μΑ) | 196 | 71 | 33.68 | 23.77 | 18.33 | 14.06 | 10.8 | 9.72 |
| Ιcorr = IPT - Idark (μΑ) | 196 | 71 | 33.68 | 23.77 | 18.33 | 14.06 | 10.8 | 9.72 |

Λαμβάνοντας υπόψη τις μετρήσεις του προηγούμενου πίνακα προκύπτουν οι γραφικές παραστάσεις icorr-R (Fig. 5) και Ισχύς- icorr (Fig. 6).

Fig. 5: Διάγραμμα ρεύματος Icorr σε συνάρτηση με διαφορετικές τιμές αντίστασης R

Διαπιστώνεται ότι όσο αυξάνεται η τιμή της αντίστασης R μειώνεται το ρεύμα του συλλέκτη iPT και άρα και το icorr . Αυτό συμβαίνει καθώς με την αύξηση της τιμής της αντίστασης μειώνεται το ρεύμα που διαρρέει το LED και άρα μειώνεται ο αριθμός των εκπεμπόμενων φωτονίων, δηλαδή μειώνεται η ένταση εκπομπής του LED. Παράλληλα, διαφαίνεται και η περιορισμένη γραμμικότητα του φωτοτρανζίστορ (αποτελείται από μη γραμμικά στοιχεία), η οποία είναι και το βασικό μειονέκτημά του.

Fig. 6: Διάγραμμα ρεύματος Icorr σε συνάρτηση με διαφορετικές τιμές ισχύος

Παρατηρείται ότι όσο αυξάνεται η ισχύς της εκπεμπόμενης ακτινοβολίας, τόσο μεγαλύτερο είναι το ρεύμα εξόδου του φωτοτρανζίστορ. Με βάση την θεωρία το φως που προσπίπτει στην βάση του φωτοτρανζίστορ αντικαθιστά κατά κάποιον τρόπο το δυναμικό που εφαρμόζεται, αφού δημιουργούνται ελεύθεροι φορείς από το προσπίπτον φως. Έτσι, ενισχύονται οι μεταβολές του ρεύματος, οι οποίες προκαλούνται από τις μεταβολές του προσπίπτοντος φωτός. Οι προαναφερθείσες μεταβολές είναι ανάλογες της ισχύος του LED. Επομένως το ρεύμα icorr είναι ανάλογο της ισχύος, όπως παρουσιάζεται και στην παραπάνω γραφική παράσταση.

**Βήμα 3**

Στο τρίτο μέρος της δεύτερης πειραματικής άσκησης πραγματοποιήθηκε μέτρηση της συγκέντρωσης και του συντελεστή απορρόφησης ουσίας σε διάλυμα. Με βάση το προηγούμενο κύκλωμα, αλλά με αντίσταση R=1kΩ, τοποθετήθηκε το φιαλίδιο με το εκάστοτε διάλυμα μεταξύ φωτοτρανζίστορ και κόκκινο LED και μετρήθηκε το ρεύμα του συλλέκτη. Αφού η τάση τροφοδοσίας ρυθμίστηκε στα +15V, η διαδικασία επαναλήφθηκε με χρήση του πράσινου LED. Τα αποτελέσματα παρατίθενται στον Πίνακας 5.

Πίνακας 5: Ρεύμα συλλέκτη για διαφορετικές συγκεντρώσεις διαλυμάτων

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Δείγμα | ΚΟΚΚΙΝΟ LED | | ΠΡΑΣΙΝΟ LED | |
| Νερό (IPTO) | 3.51 mA | | 18.34 mA | |
| C (mM) | IPT (κόκκινο) | IPT/IPTO(\*10-5) | IPT (πράσινο) | IPT / IPTO(\*10-5) |
| C1 = 0.72 | 0.44 μΑ | 12.5 | 1.31 μΑ | 7.14 |
| C2 = 0.38 | 0.65 μΑ | 18.5 | 2.8 μΑ | 15.3 |
| C3 = 0.17 | 1.13 μΑ | 32 | 3.2 μΑ | 17.4 |
| C4 = 0.03 | 538 μΑ | 15327 | 37.36 μΑ | 203 |
| C5 = X | 0.61 μΑ | 17.6 | 2.56 μΑ | 13.9 |

Στην συνέχεια, θεωρώντας ότι το φωτοτρανζίστορ αποκρίνεται γραμμικά στην φασματική περιοχή του κόκκινου και του πράσινου LED, μπορούμε να υποθέσουμε ότι η ένταση του ηλεκτρικού ρεύματος στο συλλέκτη iPT είναι ανάλογη με την ένταση της φωτεινής ακτινοβολίας I. Δηλαδή ισχύει ότι . Επιπρόσθετα, η απορροφητικότητα του διαλύματος δίνεται από την σχέση , όπου C η συγκέντρωση του διαλύματος, μα ο συντελεστής απορρόφησης και L είναι το μήκος που διανύει το φως στο διάλυμα (που στο πείραμά μας είναι το πάχος της κυβέτας L=13.8mm).

Πίνακας 6: Απορροφητικότητα LED

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | ΚΟΚΚΙΝΟ LED | | ΠΡΑΣΙΝΟ LED | |
| Δείγμα | Iout/Iin (\*10-5) | A | Iout/Iin (\*10-5) | A |
| C1 = 0.72 | 12.5 | -3.9 | 7.14 | -4.15 |
| C2 = 0.38 | 18.5 | -3.73 | 15.3 | -3.82 |
| C3 = 0.17 | 32 | -3.49 | 17.4 | -3.76 |
| C4 = 0.03 | 15327 | -0.81 | 203 | -2.69 |
| C5 = X | 17.6 | -3.75 | 13.9 | -3.85 |

Για τον υπολογισμό του συντελεστή απορρόφησης για τα δυο LED χρησιμοποιήθηκε ο τύπος . Έτσι προκύπτει ο κάτωθι πίνακας.

Πίνακας 7:Υπολογισμός συντελεστή απορρόφησης

|  |  |  |
| --- | --- | --- |
|  | ΚΟΚΚΙΝΟ LED | ΠΡΑΣΙΝΟ LED |
| Δείγμα | μαRED | μαGREEN |
| C1 = 0.72 | -392.51 | -417.67 |
| C2 = 0.38 | -711.29 | -728.45 |
| C3 = 0.17 | -1487.6 | -1602.7 |
| C4 = 0.03 | -1956.5 | -6497.6 |

Με βάση τα στοιχεία του Πίνακας 6, σχεδιάστηκε η γραφική παράσταση της απορροφητικότητας σε συνάρτηση με την συγκέντρωση, μόνο για τις συγκεντρώσεις C1 έως C4 για κάθε LED.

Fig. 7: Διάγραμμα Απορροφητικότητας- Συγκέντρωσης για κάθε LED

**Βήμα 4**

Στο συγκεκριμένο βήμα υπολογίσθηκε η άγνωστη συγκέντρωση της διαλυμένης ουσίας CX. Συγκεκριμένα, λάβαμε υπόψιν την εξίσωση της γραφική παράστασης για τα δυο LED (που ήταν παρόμοια και για τα δυο LED) και τις θέσαμε ίση με τον λόγο απορροφητικότητας και έτσι υπολογίστηκε η ζητούμενη συγκέντρωση. Δηλαδή:

Πιο αξιόπιστη μέτρηση έχουμε στην περίπτωση του μήκους κύματος του πράσινου φωτός. Σύμφωνα με τα παρακάτω διαγράμματα της θεωρίας παρατηρείται ότι το φάσμα απορρόφησης του K2MNO4 έχει μέγιστο παρά πολύ κοντά στο μέγιστο του φάσματος εκπομπής του πράσινου LED, ενώ βρίσκεται μακριά στην περίπτωση του κόκκινου.

A picture containing text, scale, device

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Fig. 8: Φάσματα εκπομπής του κόκκινου και του πράσινου LED

Chart

Description automatically generated

Fig. 9: Φάσμα απορρόφησης του K2MNO4

**ΠΕΙΡΑΜΑΤΙΚΗ ΑΣΚΗΣΗ 3 : ΦΩΤΟΜΕΤΡΟ ΚΑΙ ΟΠΤΙΚΗ ΣΥΝΔΕΣΗ**

**Βήμα 1**

Συνδέθηκε, αρχικά, το δοθέν κύκλωμα του receiver με RF = 10kΩ και P1 = 22kΩ και κάνοντας χρήση ενός καλύμματος (χαρτί) η φωτοδίοδος διατηρήθηκε στο σκοτάδι. Στη συνέχεια, μηδενίστηκε η έξοδος του ενισχυτή χρησιμοποιώντας το ποτενσιόμετρο και διατηρώντας πάντα την φωτοδίοδο στο σκοτάδι, δηλαδή Iin = Idark = 0A. Κατόπιν, αφαιρέθηκε το κάλυμμα και μετρήθηκε η τάση εξόδου, η οποία αντιστοιχεί στην ένταση που έχει το φως στο εργαστήριο. Η μέτρηση ήταν Vout = - 68mV. Το πλην στην μέτρηση οφείλεται στην αρνητική ανάδραση.

Για τον υπολογισμό της έντασης της ακτινοβολίας (Ν) έπρεπε πρώτα να μετατρέψουμε την τάση σε ένταση ακτινοβολίας χρησιμοποιώντας την σχέση , όπου I είναι το φωτόρευμα και Sλ η ευαισθησία της φωτοδιόδου. Σύμφωνα με τα δεδομένα της πειραματικής άσκησης η ευαισθησία της φωτοδιόδου στο μήκος κύματος των 650nm που μας ενδιαφέρει είναι , όπου 51μΑ/(mW/cm2) είναι η μέγιστη ακτινοβολία στα 900nm και 0.6 η σχετική φασματική ευαισθησία στα 650nm. Άρα πρέπει να υπολογίσουμε το ρεύμα εισόδου, για το οποίο ισχύει:

Ένας current to voltage ενισχυτής είναι ένας αντιστρέφων ενισχυτής, όπου το ρεύμα εισόδου του εφαρμόζεται στην αρνητική είσοδο του ενισχυτή. Αν σαν ρεύμα εισόδου εφαρμόζεται το ανάστροφο ρεύμα της φωτοδιόδου, η τάση στην έξοδο του ενισχυτή είναι ανάλογη με αυτό και συγχρόνως με την ένταση του προσπίπτοντος στην φωτοδίοδο φωτός. Επομένως το φωτόρευμα είναι I = 6.8 μΑ. Όποτε προκύπτει ότι η ένταση της φωτεινής ακτινοβολίας που μετρήθηκε στο εργαστήριο είναι:

Σύμφωνα με την πειραματική άσκηση η ένταση της ηλιακής ακτινοβολίας μια καθαρή μέρα είναι 1kW/m2. Η επί τοις εκατό διαφορά σε σχέση με την ακτινοβολία που μετρήσαμε είναι η εξής:

Αξίζει να σημειωθεί ότι παρατηρείται μεγάλη διαφορά μεταξύ της ηλικιακής ακτινοβολίας σε μια καθαρή μέρα και της έντασης της ακτινοβολίας κατά την διάρκεια εκτέλεσης του εργαστηρίου. Συγκεκριμένα η μετρήσιμη ακτινοβολία αποτελεί περίπου το 0.222% της έντασης της ηλιακής ακτινοβολίας μιας καθαρής μέρας. Αυτό οφείλεται στο γεγονός ότι το εργαστήριο είναι μια κλειστή αίθουσα, με αποτέλεσμα να περιορίζεται η ηλιακή ακτινοβολία που εισέρχεται στην αίθουσα. Παράλληλα, την μέρα διεξαγωγής της εργαστηριακής άσκησης ο καιρός ήταν συννεφιασμένος με βροχή, περιορίζοντας ακόμα περισσότερο την είσοδο ηλιακής ακτινοβολίας. Λαμβάνοντας υπόψη και διάφορους παράγοντες που επηρεάζουν μια πειραματική μέτρηση, όπως μη ιδανικά στοιχεία, σφάλματα μετρητικών οργάνων και ο ανθρώπινος παράγοντας, σε συνδυασμό με όσα προαναφέρθηκαν αιτιολογούν την μεγάλη διαφορά στην ένταση της ηλικιακής ακτινοβολίας μιας καθαρής μέρας με την αντίστοιχη του εργαστηρίου.

**Βήμα 2**

Χωρίς να πειράξουμε το υπάρχων κύκλωμα προστέθηκε το κύκλωμα του transmitter έτσι ώστε το LED να δείχνει προς τη φωτοδίοδο και να υλοποιηθεί με αυτό τον τρόπο η οπτική σύνδεση (Fig. 10).

![Diagram

Description automatically generated with low confidence](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4S5IRXhpZgAATU0AKgAAAAgABgALAAIAAAAmAAAIYgESAAMAAAABAAEAAAExAAIAAAAmAAAIiAEyAAIAAAAUAAAIrodpAAQAAAABAAAIwuocAAcAAAgMAAAAVgAAEUYc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAFdpbmRvd3MgUGhvdG8gRWRpdG9yIDEwLjAuMTAwMTEuMTYzODQAV2luZG93cyBQaG90byBFZGl0b3IgMTAuMC4xMDAxMS4xNjM4NAAyMDIyOjAxOjA4IDEzOjIxOjA0AAAGkAMAAgAAABQAABEckAQAAgAAABQAABEwkpEAAgAAAAMwMAAAkpIAAgAAAAMwMAAAoAEAAwAAAAEAAQAA6hwABwAACAwAAAkQAAAAABzqAAAACAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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ilj9xSARbXd/DVhdP3Nin27Y61p220nNAjN/s1h0p39nP6VvwwK3UVY8kelWI5cWrj+E/lUv2Q/3f0roTajsBUf2UelAGGtmTUosyO1bItlHapYrUP1FAGH9hPpQ2mq2MjJByDXRfYfYUv2H/ZoA5r7AB8xBzUiw7vp3rfbT93Haoo9N8t2Yn73btVAYjQletOEZHatn7Gvdc0z7L7VIFBYTnNXbdT3p4t2HarMVuduciqAs2o5rRt6owxFcEVfhXFBJbVRU+73FQx5apNopiHbivX86R2P93P0NH61C33sAYpADOvc0mc9RiopDmomkxy0ihMZ69MDJzQK+l2fNX7XviCfUtZ8O+FLIF52HnlM5zJI2yMflzX0z4W0OPw14f0zSIP9TY28VuvvtGK+T/Aefi9+1Bd6vjztM0uV7hT/AAhYxthH5819fQjPGfp7VpPZRPEy797Vq4l/adl6I0VwFyOaNw7cUyPIGKkqD3B25h04p+V/ummrzUlACAZpaFFO2e9BY1h8uRUVT42nHao/LFBBHtp/NN53YqTdQWCin7aYtSUAFJtp34UcUE2G45zSbTT9p25pFYnsKQj4PguLzwxfLf6d80TH99b84YfSvWPDHiS08QWons5vmUfvIn4ZD9K8ltdQMjGOUHzR8rK3BH4UJHdaTdC806Uwz5zleh+or8rynOKuFfsMRsevisM4vnoq67H0NYXzx7QTxWxDeZryfwf8SrPWCtregWV8P4W4Rvoe1eh282WADZJ6YPB/Gv0ilVjVjzQd0eYmpbG59pPqKY10BVZXDoCDzQ0ddAxWuec1Xkkyuac0ZqtIjAYpDI2qvJg1I2agY+9AEDL9Kj21O2PSk2UARx/M2K0bcmqscYByBVuMbelAjRhc9jV9XyuTWZbyBauK+RimBYEmKTzfpVbdSbqoktxsJOlW7baaylkP8NXLeTGKANNVB7VJ5I96it5A/WrS89qoCBosDFMaH5c4q2eaaTkYoAp+QKT7OPSrNPVQe9SBV+zj0p8dqAMVYVQasRxg9hVIkijhAxwamSErVlI93QCpQmO1MRAqlegqXyx61J5fuKcVHYY+tBZAyqOhqBh3q1IoToA30qDbnvSIKzJXmf7QXjoeBfhxqciSKuo6gDZ2gHB3N95h/ur+tepMp3hR+favkL4jXU/7QXxy0/w1pkm7RLORoVk6rsBzNMfr0FXFXd3seVmFd0qXJD4paI9K/ZG8Dt4d+Hs2tXCbLnW5Q8ZPUQJwh/E8175DHiq+n6fb6bZ29naxLFbW8axRxqOFVRwP61oRx4pSd3c7cLRWHpRpR6DlX3qVQS2KQR7aep5zxSOsdgin0A07bQAKKk49KYOKdkUAI6ljkDFM2mpG+b+LFB9hQBDtOc4oC+tTKuepNIVyuaAI8Yp9Cx5p+00gBVJpOaex8vrQQe1ADMcYyaFzTttLtIbFID5R8afD+DXFa7tAtvfg53AYDfWvMZFvdFumtdQha3kH3d/Rvoa+j5rXcPWue8QeGrXWrVob2HzV/hPdfoa+TzDJqeLvOGkj06OI9mrPY8NuLWK++cYEg/iU4zW74a8f6l4c2wTKb22H/LKRufwNV9e8A6l4cZ57Um+sh1K/6xfqO9Ysd9FeR4kG7Bxjuv4V8jTqYzKZ8ktgxGHhiFz0naR9A+E/Gum+JI1NpOom7wSHDj8O9dYuJFyOPqa+S5vPs5lnt3ZHXpJGcMPxrvvCPxwvtICW2uRtdQD/AJbx/fT/AHh3/CvssFnNKukqjszylKcXyVVZnu5iB9ahkhz0FQaB4h0/xLZLc6fdR3CMPuqfmB+la3l9R3Havo4yU1eJp6GM1qfSqzWv+zXQGIGoja5pjOeMJPak8muh+xj0qH7CvpQK5jrFhsGpVjx1NT3du8TDauWzirX2fd1UCgZXVRVhfu5pRHjtUoUgYwKAI/wpKl2Um2rER/pU8bFcYqPy/enLndgUEmhBJt6VcjmfGM5b2rMjfFWYrj5cAYplGj5lNLEVDuFL5lBIvmGgOR2FNPtS7R60gLKmp4XB71VRiWxVmPavSqAvxYZdxOB7VKvNVEOenSrMbf3qAJdo9KAB35+tJupzKqrkmkBBIvzYHFMZWGD2p+ec0khxGOCqf3j9MmgTslqeTftIfEg+AfAb29rciLVtTBt7f+9GgOHk/wAP61jfsp/DFvCfg9/Ed9H/AMTTXI90YYfNFa9gfQt3rzTV4H/aF/aGjskdpNBs5Sj+i2sJw5/4G3T2r7BjiSNFRFCRqoRUUYAUdAPYVtL3Y8p8/hV9cxMsS9o6R/zFitxnPNW1jpsSHbu7VYVfmxWR9CM2ClCgdhUu2l20XAZsx60Z7Z5+lSUu33NAETZFPU7lz09j1p20GgKO/J9T1oAaqhqUNilC7V9T7UMuO9MA20vbGRRS4DdBQAgGO1O2ilXmlCnOT9360gG7R3yaQYHc1IqlmxkUi5PYUwG7aO+c05lI7imbvYVAHkDQ7fWoprcSAgDP1rRaOo9ntisS7nM3mllWJXp6VwPij4e2Wrs00afY73OfNjXAP1r1+WFZOorIvtOBbheK5q2Hp4iPLNXNKdSVPVHzVrWkar4cl23UBaI/dmQEqazGKSDIGfUd6+h77T1ljZZUEit1DDNed+IPhda3rPPpzmzuD/yz5Kfl/wDXr5DE5JOm+fDu/kdVSVPEJqpozg9H1K+0G8F3plzJazZydh4P4V7N4L+O0V15VprieVL2uE5X8a8S1KxvdFmMd7bvCwP3gPlIqurxzBTkH6HkVzYfF18PKy0fZnjzlPCv3veifaFnfQ6hCk9vIs0DDIkQ5H51Z3AtgCvlDwj8QNQ8MTJ5NyQM42sSUcehGeDXuXg/4taT4gZbe4YWF8f+WcjfKfoa+twuZ0a/uS0l2O7lUo88HdHoPlqaXya5nW/Gn9lwo1ra/aizY37vlxWrofii01i3BZhBcf8APNq9VSi+pm4sv/Z14yM855qMwZ7Ve44H8R6Um32qiTOa22+tDR4q+VBphizQVcoeXSNGRVzyvamtH7VYFTZRs5z0qfy6Tb7UriIxkdqljfFJt9qBx2ouMn80e9SIdy5JqtubdipUO0YpCLS4p6YbqKjUVYi6dOaokkjTac1Oq+1IFAbFTrH82KoAjwy8gg+1TL8ue/1poJBzUmz/AGhQA9WzSbgTtLZFM+6uaa2xW6HNSAbi3SuA+OfjE+B/htq99HN5d7cJ9ktCDyJG4JH0Fd6c9Bye+K+Vv2jNaufiF8TNE8DaUwkkt5VgO05BuJDzn2Rf1rWEeZ6nl5jXdGg+X4novVna/sh+CzpXhO+8RTIFl1VvJgc/88EOCfxNfQEa7qzPDei2/hzQdO0m1VVt7GBYFAHYevueprbhjHepbuzpwlBYejGmuiJYsbc4+WpVx170Iu3jjFSr97IFI6w2n0pNq7f4s071+Y07ad2c8VIELIQ2MUufY09s+vPr2qPLUwFo59KWm7vlzk0wHDJOVIU+9MY/3lpOT1waftb60AG4U4fN3I+lG0elLgrSABxTmxuztB/2RTad7jg+tMAbaxz0+lAXbnk05cGk9aAApmm+Uacp+bDEinVIHl00W3pVdhitS4irNmRl6CoLIXqrP8wwasMfWq81AGLfW4Ixk1jzW6qrEDB+tb93zWVcYwRWRRzuoWEV5F5VxEs0eMBXGcV5v4l+FrLvu9HfDjrbseT9K9cmiBqlJCCcnrXFiMHSxHxLUH7ysz5xkeS3kaKeJoph9+Jhgk+tdh4HtTq07KWU7F3Kzda7zxJ4Rs/EUZE8Yiu1GY51wCP0rzQpd+Eb4yx4lMMu19ueRXz9TLpQdvuZzUYyw9S8fhZ6dZ+Nl061mtNU/eWw6Srzt+tGk+MtMvpBtumgbJA8wcGtD4Y+GbHx1Z6jd3ccZjC5EA5cn6Vq3nw68M6LpNyhmW5umG5I9pDJ+NevQlJRtLc9eUU1dGto/jK70/G6RbqDurN/I13Ol+JLLVkUxSKpP8LnFfIOpeLZvD880cE8iRqcIh5FP0/4y3sE0a3C7x6qMH+derGUjjlBH2dx0/XqKUqO1fP3hn40PLhWmki/66civWfD/j601VVWULDKerBsrWikjNwZ0rJimmPNTriRcj5h/snNLtFaklTyx6VE0WKubKUxA1AFHZTfL+tXPJqNosUFFfHzCnrmn+TUix0AOXNWoUBeoVWrcCfMasgeD83NTjIOc0zbuOcVMqg/w0wHinfL6UmAGxSbW9P1oAdICRimrgNuJyaRt+7FNZ14ySfXFIDnfH/iqHwP4P1bXbghY7WIlF7vJ0VB7k14H+yj4NuPEHibV/G2qq0rxO8cDsM753/1j59u1L+1l4un1bWdJ8G2G5pVdLiWFT96Zv8AVIfcdTX0D8O/B0XgLwXpWhwgA2sAWUqfvysuZG/Otfhj6nz9vrmOv9in+Z1EKnPHrnFXYx8uTUNsg25HNWtq4xzWZ9AP+oH4VIq4XK/rTFUfWpdvGOlADFBOalzxjFNHFO27W56UgEPJ9vTtTZFVlJ3fTipcbsY70xmOAMdKAK3IbFLu4xxUki5ORVeQlOfvD2qgH7m254pV5pi8qOeKelIofupzSbu1Mqbj0pAMUE1Jx2yPrQuPQ07jaT9760wIxxS0ZG7Hb17UlBIsnPPSnKc0Fd4O04b/AGqbt25pDR//2Q==)

Fig. 10: Κύκλωμα transmitter-receiver

Ακολούθως, μειώσαμε την ένταση του LED, μεταβάλλοντας την αντίσταση Rs, και καταγράψαμε για την εκάστοτε μεταβολή της αντίστασης την τιμή της τάσης εξόδου (Vout). Υπολογίστηκε, επίσης, για κάθε τιμή της αντίστασης, το ρεύμα που εξέρχεται από την φωτοδίοδο Iin και η ζητούμενη ισχύς. Σύμφωνα με την θεωρεία, λόγω της άπειρης αντίστασης του τελεστικού ενισχυτή όλο το ρεύμα Iin περνάει από την αντίσταση Rf και λόγω της αναστρέφουσας συνδεσμολογίας του τελεστικού ενισχυτή ισχύει ότι . Αφού οι τιμές της αντίστασης είναι γνωστές και οι τιμές της τάσης τις μετρήσαμε στο εργαστήριο υπολογίζεται το Iin. Όσο αφορά τον υπολογισμό της ισχύος πρέπει πρώτα να υπολογίσουμε την ισχύ σε Watt. Αυτό γίνεται μέσω του τύπου . Ύστερα για να μετατρέψουμε την ισχύ του φωτός από Watt σε lumen, χρησιμοποιήθηκε ο τύπος , όπου για το LED της συγκεκριμένης άσκησης δίνεται ότι . Επομένως προκύπτει ο παρακάτω πίνακας (Πίνακας 8).

Πίνακας 8: Μετρήσεις με το ολοκληρωμένο κύκλωμα transmitter-receiver

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Rs (kΩ) | 1.0 | 2.2 | 3.9 | 5.1 | 6.2 | 7.5 | 9.1 | 10 |
| Vout (V) | -9.32 | -4.046 | -2.22 | -1.47 | -1.173 | -0.945 | -0.771 | -0.69 |
| Iin(μΑ) | 932 | 404.6 | 222 | 147 | 117.3 | 94.5 | 77.1 | 69 |
| Ισχύς (Ιm) | 0.3560 | 0.0671 | 0.0202 | 0.0089 | 0.0056 | 0.0037 | 0.0024 | 0.0020 |

Fig. 11:Καμπύλη φωτόρευμα-ισχύος

Με βάση το άνωθι διάγραμμα παρατηρείται ότι η καμπύλη εμφανίζει μια είδους γραμμικότητα. Λαμβάνοντας υπόψη την θεωρεία, το φωτόρευμα είναι ανάλογο της έντασης του φωτός (Ν), της οποίας μονάδα μέτρησης είναι το Watt/επιφάνεια. Δεδομένου ότι η επιφάνεια είναι σταθερή, το φωτόρευμα είναι ανάλογο της ισχύος και άρα η μεταξύ τους σχέση είναι γραμμική.

**Βήμα 3**

Στο συγκεκριμένο κομμάτι της εργαστηριακής άσκησης διατηρήθηκε το ίδιο κύκλωμα με την διαφορά ότι στα άκρα του πομπού συνδέθηκε η γεννήτρια κυμματομορφών, η οποία ρυθμίστηκε να δίνει ως έξοδο τετραγωνικό σήμα από 0V έως 12.5V συχνότητας 1kHz. Έπειτα, η γεννήτρια συνδέθηκε με Rs = 1kΩ και CF =1nF, ώστε να δημιουργηθεί μια οπτική σύνδεση και να μελετηθεί η μετάδοση του σήματος. Για αυτό τον λόγο, συνδέσαμε τα κανάλια του παλμογράφου σε DC σύζευξη, το ένα στην είσοδο του transmitter και το άλλο στην έξοδο του receiver, για να καταγραφούν σε χρονική αντιστοιχία οι κυμματομορφές και να διαπιστωθεί αν ο δέκτης λαμβάνει ότι του στέλνει ο πομπός. Κατόπιν, ρυθμίστηκε η έξοδος της γεννήτριας στα 10kΗz και έπρεπε να υπολογιστεί ο χρόνος ανόδου του σήματος εξόδου, ο οποίος ορίζεται ως ο χρόνος που χρειάζεται για να μεταβεί η κυματομορφή από το 10% στο 90% της σταθερής τιμής. Όμως λόγω ορισμένων προβλημάτων στο κύκλωμα με τις καλωδιώσεις και στα μετρητικά όργανα του εργαστηρίου δεν έγινε εφικτό να παρθούν οι ζητούμενες κυμματομορφές στο καθορισμένο χρόνο, οπότε ορισμένες τιμές μας δόθηκαν από τους υπεύθυνους του εργαστηρίου και για αυτό δεν έχουμε παραθέσει φωτογραφίες κυμματομορφών στην αναφορά.

Συγκεκριμένα ο χρόνος ανόδου είναι tr=36μs. Σύμφωνα με το datasheet όμως ο χρόνος ανόδου δίνεται στα 100ns. Η διαφορά μεταξύ των δυο χρόνων οφείλεται, αρχικά, στο πειραματικό σφάλμα, καθώς ο τελεστικός ενισχυτής και τα υπόλοιπα στοιχεία του κυκλώματος δεν είναι ιδανικά. Δεύτερον, η μέτρηση του datasheet έχει παρθεί κάτω από συγκεκριμένες συνθήκες, θερμοκρασίας-υγρασίας κλπ., που εμείς στο εργαστήριο δεν ικανοποιούσαμε. Επίσης, στην εργαστηριακή άσκηση χρησιμοποιήθηκε LED ως πηγή φωτός με διαφορετικό φάσμα συχνοτήτων από το αντίστοιχο του datasheet.

Ακολούθως, αυξήθηκε η συχνότητα της γεννήτριας μέχρι το σήμα εξόδου να μειωθεί στο 0.707 του αρχικού πλάτους. Η συγκεκριμένη συχνότητα ονομάζεται συχνότητα αποκοπής και καθορίζει το bandwidth της διάταξης. Η συχνότητα αποκοπής μετρήθηκε ως fc = 19kHz. Εφόσον η συχνότητα αποκοπής είναι 19kHz, που αποτελεί την μέγιστη συχνότητα στην οποία μπορούμε να έχουμε μετάδοση, τότε και το bandwidth της διάταξης ισούται περίπου με 19kbps. Η συχνότητα αποκοπής και συνεπώς το bandwidth του οπτικού καναλιού εξαρτάται από το υλικό της φωτοδιόδου. Στη φωτοδίοδο δημιουργείται μια μικρή χωρητικότητα, λόγω της επαφής PN, η οποία καθορίζει τη μέγιστη συχνότητα αποκοπής. Γι’ αυτό στις τηλεπικοινωνίες συνήθως χρησιμοποιούνται οι φωτοδίοδοι Schottky οι οποίες δεν έχουν επαφή PN, αλλά γίνεται επαφή ενός ημιαγωγού και ενός μετάλλου, γεγονός που μειώνει την χωρητικότητα και επιτρέπει μεγαλύτερες συχνότητες αποκοπής άρα και bandwidth.

Αν δεν ακολουθούσε το κύκλωμα ενίσχυσης, τότε το bandwidth θα ήταν διαφορετικό. Αυτό συμβαίνει, διότι το φωτόρευμα της διόδου διέρχεται από τον κλάδο της ανάδρασης του τελεστικού (ο οποίος έχει μεγάλη αντίσταση εισόδου), και περνάει μέσα από το παράλληλο κύκλωμα RC, το οποίο συμπεριφέρεται ως χαμηλοπερατό φίλτρο, περιορίζοντας έτσι το bandwidth. Αν δεν υπήρχε ο τελεστικός, τότε η συχνότητα αποκοπής θα εξαρτιόνταν από το υλικό της φωτοδιόδου και πιο συγκεκριμένα από την χωρητικότητα της επαφής PN.

**ΠΕΙΡΑΜΑΤΙΚΗ ΑΣΚΗΣΗ 4 : ΒΑΣΙΚΕΣ ΑΡΧΕΣ ΟΠΤΙΚΩΝ ΙΝΩΝ ΚΑΙ ΟΠΤΙΚΩΝ ΕΠΙΚΟΙΝΩΝΙΩΝ**

**Βήμα 1**

Υλοποιήσαμε το ζητούμενο κύκλωμα με αντίσταση R1 = 560Ω, όπως παρουσιάζεται στο Fig. 12. Ο πομπός συνδέθηκε στην άκρη του breadboard, ώστε η έξοδος του να κοιτάει προς την εξωτερική πλευρά.

Diagram

Description automatically generated

Fig. 12: Κύκλωμα οπτικής ίνας

Στην είσοδο 1 του πομπού συνδέθηκε το θετικό άκρο της γεννήτριας συχνοτήτων και στην είσοδο 2 το αρνητικό άκρο. Δώσαμε σήμα εισόδου τετραγωνικό παλμό ύψους 6V (peak to peak) και συχνότητας 100kHz. Επιβεβαιώσαμε ότι ο πομπός λειτουργούσε, καθώς μέσω ανάκλασης παρατηρήσαμε κόκκινο φως το οποίο εκπέμπει η πηγή LED, που περιέχεται στον πομπό. Στη συνέχεια, συνδέσαμε το ένα κανάλι του παλμογράφου στην είσοδο του συστήματος και το δεύτερο στην έξοδο. Προβάλλαμε τα δυο κανάλια του παλμογράφου σε χρονική αντιστοιχία για τις διάφορες τιμές συχνοτήτων και υπολογίσαμε τα στοιχεία των κυμματομορφών, όπως παρουσιάζεται παρακάτω, αφού συνδέσαμε τα καλώδια της οπτικής ίνας στον πομπό και στον δέκτη.

Graphical user interface

Description automatically generated

Fig. 13: Κυμματομορφές γιa 100kHz

* Η τάση εισόδου είναι:
* Η τάση εξόδου είναι:
* H περίοδος είναι:

Με βάση το Fig. 13 παρατηρείται μια εξασθένιση πλάτους του σήματος εξόδου σε σχέση με το αντίστοιχο της εισόδου, λόγω της ύπαρξης θορύβου. Η διαφορά φάσης των δυο σημάτων είναι 90ﹾ.

Graphical user interface

Description automatically generated

Fig. 14:Κυμματομορφές για 1MHz

* Η τάση εισόδου είναι:
* Η τάση εξόδου είναι:
* H περίοδος είναι:

Με βάση το Fig. 14 παρατηρείται μια εξασθένιση πλάτους του σήματος εξόδου σε σχέση με το αντίστοιχο της εισόδου, λόγω της ύπαρξης θορύβου αλλά ταυτόχρονα διαφαίνεται και μια παραμόρφωση του σήματος.

A picture containing text, device, control panel

Description automatically generated

Fig. 15:Κυμματομορφές για 2MHz

* Η τάση εισόδου είναι:
* Η τάση εξόδου είναι:
* H περίοδος είναι:

Με βάση το Fig. 15 παρατηρείται μια εξασθένιση πλάτους του σήματος εξόδου σε σχέση με το αντίστοιχο της εισόδου, λόγω της ύπαρξης θορύβου αλλά ταυτόχρονα διαφαίνεται και μια πολύ έντονη παραμόρφωση του σήματος (μεγαλύτερη από την αντίστοιχη περίπτωση των 1MHz).

A picture containing text, control panel

Description automatically generated

Fig. 16: Κυμματομορφές για 5MHz

* Η τάση εισόδου είναι:
* Η τάση εξόδου είναι:
* H περίοδος είναι:

Με βάση το Fig. 16 διαπιστώνεται ότι το σήμα εξόδου δεν έχει πλέον παλμική μορφή και δεν είναι εφικτό να εξαχθεί πληροφορία.

*Γενικές παρατηρήσεις όσο αφορά τα διαγράμματα*

Οι απώλειες στις οπτικές ίνες έχουν ως αποτέλεσμα την εξασθένηση του οπτικού σήματος και την παραμόρφωσή του. Το πρώτο καθορίζει το πόσο μακριά μπορεί να διαδοθεί το σήμα με επίπεδο έντασης αναγνωρίσιμο από το δέκτη και γενικότερα τις ανάγκες οπτικής ενίσχυσης του σήματος σε ένα δίκτυο. Ο βαθμός παραμόρφωσης του σήματος θέτει περιορισμούς στην πυκνότητα πληροφορίας, η οποία μπορεί να μεταφερθεί από την ίνα. Οι σημαντικοί αυτοί παράγοντες, οι οποίοι καθορίζουν τα κύρια ποιοτικά χαρακτηριστικά του δικτύου αναπτύσσονται στη συνέχεια με έμφαση στη φυσική αιτιολογία τους. Πιο συγκεκριμένα, παρατηρούμε ότι αυξάνεται η συχνότητα, τόσο μεγαλύτερη είναι και η εξασθένηση του σήματος. Η μεγαλύτερη εξασθένηση παρατηρείται στην τελευταία περίπτωση, με συχνότητα ίση με 5 ΜΗz, όπου το σήμα εξόδου έχει χαθεί, το οποίο καθιστά αδύνατη την εξαγωγή πληροφορίας.

**Βήμα 2**

Εφαρμόσαμε στην είσοδο του συστήματος τετραγωνικό παλμό ύψους 6V peak to peak και συχνότητας 100 kHz. Μετρήσαμε την ισχύ στην έξοδο της πηγής χωρίς την ίνα. Στη συνέχεια συνδέσαμε το καλώδιο της οπτικής ίνας στον πομπό, ευθυγραμμίσαμε την ίνα και μετρήσαμε στο άλλο άκρο της την ισχύ του σήματος. Έπειτα, συνδέσαμε το δεύτερο καλώδιο της οπτικής ίνας με το πρώτο, μέσω του ειδικού συνδετήρα και μετρήσαμε την ισχύ στην έξοδο. Επιπρόσθετα, ως μονάδα μέτρησης της εξασθένησης του σήματος λόγω απωλειών χρησιμοποιείται το dBm, το οποίο εκφράζει το μετρούμενο ποσοστό ισχύος επί του 1mW. Συνήθως στις μετρήσεις των οπτικών ινών ο αριθμός είναι αρνητικός, επειδή τα επίπεδα ισχύος είναι μικρότερα του 1 mW. Ο τύπος που αντιστοιχίζει την ισχύ Ρ σε Watt με x dBm είναι:

Επίσης ισχύει:

Τα αποτελέσματα παρουσιάζονται στον Πίνακας 9 και το αντίστοιχο ιστόγραμμα στο Fig. 17.

Πίνακας 9: Μετρήσεις οπτικής ίνας

|  |  |  |
| --- | --- | --- |
| Είδος μέτρησης | Ισχύς (dBm) | Ισχύς (μW) |
| Στην έξοδο της πηγής χωρίς την ίνα | -27.6 | 1.738 |
| Στην έξοδο της οπτικής ίνας 1m | -31.38 | 0.728 |
| Στην έξοδο της οπτικής ίνας 2m με ενδιάμεσο συνδετήρα | -34.25 | 0.376 |

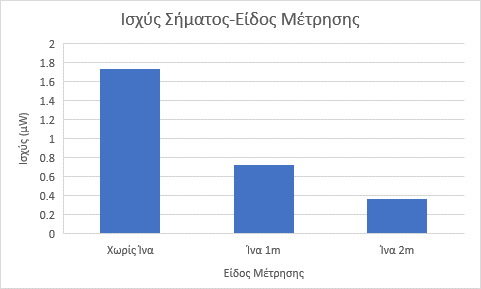


Fig. 17:Ιστόγραμμα ισχύος με είδος μέτρησης

Παρατηρώντας ότι εισάγοντας και αυξάνοντας το μήκος της οπτικής ίνας για την επικοινωνία του πομπού με το δέκτη, μειώνεται η ισχύς του σήματος εξόδου, δηλαδή η ισχύς που λαμβάνει ο δέκτης. Στην πρώτη περίπτωση που μετράμε κατευθείαν την ισχύ στην έξοδο της πηγής έχουμε την μεγαλύτερη τιμή της ισχύος, το οποίο είναι λογικό, καθώς μετράμε την ισχύς της οπτικής ακτινοβολίας που εκπέμπει το LED του πομπού χωρίς να παρεμβάλλεται κάτι ενδιάμεσα, συνεπώς χωρίς απώλειες. Κατόπιν, τοποθετώντας την οπτική ίνα 1m μειώνεται η ισχύς που μεταφέρεται από τον πομπό και λαμβάνεται από τον δέκτη, λόγω των απωλειών στις οπτικές ίνες, που οδηγούν σε εξασθένιση του οπτικού σήματος. Συνδέοντας μέσω του ειδικού συνδετήρα ένα δεύτερο καλώδιο οπτικής ίνας 1m, δημιουργώντας συνολικά οπτική ίνα μήκους 2m, μειώνεται περαιτέρω η ισχύς της εξόδου. Αυτό είναι λογικό, καθώς οι απώλειες στις οπτικές ίνες εκφράζονται ως dB/km, συνεπώς αυξάνοντας το μήκος της οπτικής ίνας στην οποία διαδίδεται το σήμα αυξάνονται και οι απώλειες.

Αξίζει να σημειωθεί ότι στις παραπάνω περιπτώσεις, το καλώδιο της οπτικής ίνας είναι τεντωμένο για να μετρηθεί η ισχύς εξόδου. Ως φυσικό επακόλουθο οι απώλειες δεν οφείλονται στην αποσύζευξη ισχύος λόγω καμπύλωσης της οπτικής ίνας, αφού δεν καμπυλώνεται. Ωστόσο, παρατηρούνται απώλειες λόγω απορρόφησης της ακτινοβολίας στην εσωτερική δομή του υλικού και λόγω σκέδασης του φωτός στα μόρια του πυρήνα της οπτικής ίνας. Αυτό έχει ως αποτέλεσμα κάποιες ακτίνες του μεταδιδόμενου φωτός να προσπίπτουν στην επιφάνεια που διαχωρίζει τον πυρήνα με τον μανδύα υπό γωνία μικρότερη από την κρίσιμη, να διαθλώνται και να εξασθενούν στο μανδύα.

Ακολούθως, κάμψαμε την ίνα 1m, με διάφορες ακτίνες. Η κάμψη επιτυγχάνεται με περιστροφή της ίνας γύρω από κύλινδρο μεταβαλλόμενων ακτινών, όπως παρουσιάζεται στο Fig. 18.Τα αποτελέσματα των μετρήσεων παρουσιάζονται στον Πίνακας 10 και το απαιτούμενο διάγραμμα στο Fig. 19.

![A picture containing indoor

Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4SvARXhpZgAATU0AKgAAAAgABgALAAIAAAAmAAAIYgESAAMAAAABAAEAAAExAAIAAAAmAAAIiAEyAAIAAAAUAAAIrodpAAQAAAABAAAIwuocAAcAAAgMAAAAVgAAEUYc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAFdpbmRvd3MgUGhvdG8gRWRpdG9yIDEwLjAuMTAwMTEuMTYzODQAV2luZG93cyBQaG90byBFZGl0b3IgMTAuMC4xMDAxMS4xNjM4NAAyMDIyOjAxOjA4IDE4OjI5OjU0AAAGkAMAAgAAABQAABEckAQAAgAAABQAABEwkpEAAgAAAAMwMAAAkpIAAgAAAAMwMAAAoAEAAwAAAAEAAQAA6hwABwAACAwAAAkQAAAAABzqAAAACAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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Fig. 18:Κύλινδρος κάμψης

Πίνακας 10: Ισχύς με κάμψη

|  |  |  |
| --- | --- | --- |
| Ακτίνα κάμψης Ίνας | Ισχύς σήματος (dBm) | Ισχύς σήματος (μW) |
| Χωρίς κάμψη | -31.38 | 0.728 |
| Ακτίνα 5cm | -31.96 | 0.637 |
| Ακτίνα 4.5cm | -32 | 0.631 |
| Ακτίνα 4cm | -32.05 | 0.624 |
| Ακτίνα 3.5cm | -32.12 | 0.614 |
| Ακτίνα 3cm | -32.27 | 0.593 |

Fig. 19:Διάγραμμα ακτίνας κάμψης-ισχύος

Σύμφωνα με τα πειραματικά δεδομένα, διαπιστώνεται ότι όσο πιο μικρή είναι η ακτίνα κάμψης, τόσο μεγαλύτερες είναι οι απώλειες και άρα τόσο μικρότερη η ισχύς εξόδου του σήματος. Η κάμψη των ινών πέρα ενός ορίου έχει αποτέλεσμα την απώλεια ενέργειας και κατ’ επέκταση την εξασθένιση της κυματοδηγούμενης ακτινοβολίας. Όταν η ίνα καμπυλώνεται λαμβάνει χώρα απόζευξη ισχύος σε ακτινοβολικούς τρόπους διάδοσης, λόγω της τοπικής διαταραχής των συνθηκών της κυματοδήγησης. Όταν η κάμψη της ίνας είναι μεγαλύτερη από μία τιμή καμπυλότητας, έχει ως αποτέλεσμα να μην πληρείται η συνθήκη ολικής ανάκλασης, με αποτέλεσμα να παύει η κυματοδήγηση.

**Βήμα 3**

Στο συγκεκριμένο βήμα της τέταρτης εργαστηριακής άσκησης, συνδέσαμε το ένα κανάλι του παλμογράφου στην είσοδο του συστήματος και το δεύτερο κανάλι στην έξοδο του συστήματος. Έπειτα συνδέσαμε το καλώδιο της οπτικής ίνας 1m στον πομπό και το δέκτη. Μειώσαμε, κατόπιν, σταδιακά το ύψος του παλμού εισόδου έως ότου η κυματομορφή εξόδου είναι σχεδόν ευθεία, δηλαδή ο δέκτης να μη λαμβάνει κανένα σήμα και καταγράψαμε την τιμή της ελάχιστης τάσης και της ισχύς του σήματος στην έξοδο της οπτικής ίνας με το φωτόμετρο. Τα αποτελέσματα καταγράφηκαν στον Πίνακας 11.

Πίνακας 11:Ελάχιστη τάση και ισχύς

|  |  |
| --- | --- |
| Ελάχιστη τάση εισόδου στο δέκτη Vmin (V) | 5 (peak to peak) |
| Ελάχιστη ισχύς που μπορεί να μετρήσει ο δέκτης Pmin (dBm) | -33.85 |

Πίνακας 12:Τιμές απωλειών κατασκευαστή

|  |  |  |
| --- | --- | --- |
| Απώλειες σε dB | Minimum | Maximum |
| Απώλειες / μέτρο ίνας | 0.19 | 0.43 |
| Απώλειες / σύνδεση | 0.7 | 2.8 |

Με βάση την αρχική ισχύ της πηγής χωρίς ίνα, την ελάχιστη ισχύ που απαιτείται στο δέκτη και τις τιμές του κατασκευαστή (Πίνακας 12), για να υπολογισθεί σε πόσα μέτρα καλωδίου οπτικής ίνας του 1m θα χρειαζόταν ένας ενισχυτής σήματος για περαιτέρω μετάδοση σήματος, ισχύει ότι:

Άρα θα χρειαζόταν ενισχυτή σήματος περίπου στα 3m οπτικής ίνας του 1m αν οι συνδέσεις στον πομπό και στον δέκτη ήταν ιδανικές (θεωρώντας τις μέγιστες τιμές απωλειών). Το προαναφερθέν αποτέλεσμα δεν λαμβάνει υπόψη τις απώλειες στις συνδέσεις πομπού και δέκτη με την οπτική ίνα. Αν συνυπολογίζονταν οι συγκεκριμένες απώλειες θα ίσχυε ότι:

Επομένως θα χρειαζόμασταν ενισχυτή σήματος στο 1m οπτικής ίνας αν οι συνδέσεις στο πομπό και στο δέκτη δεν ήταν ιδανικές (θεωρώντας τις μέγιστες τιμές απωλειών).